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Public Safety Radio System

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Public Safety Integration Center

A Major Qualifying Project Report
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science

by:

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Date: 9 January, 2009

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Abstract

The goal of this project was to create a Public Safety Integration Center (PSIC). The PSIC is a radio laboratory whose goal is to encourage the betterment of public safety communications and interoperability. It allows students to perform radio related projects, hardware manufacturers to demonstrate their equipment, and radio equipment to be tested with respect to integration and interoperability. In order to achieve this goal, equipment donated by SAIC was studied, reverse engineered, and reconfigured to suit the needs of the PSIC.

Introduction

The Public Safety Integration Center (herein referred to as the PSIC) is a laboratory, test bed and prototype demonstration environment for public safety radio applications. The center was started with equipment donated by SAIC, but will be expanded with donations and purchases from other companies.

The PSIC is designed for use by academics, industry manufacturers and public safety officials for a variety of applications. The academic purposes include radio integration related MQPs, graduate research, and educational demonstrations. Industry manufacturers can use the center to test interoperability between their equipment and other company's products as well as gain essentially free marketing for their equipment. Public safety officials looking to purchase new equipment can use the PSIC to test for compatibility issues they may have with current equipment and overall functionality.

The current academic application hosted by the PSIC is the development of the TACSTACK. Essentially, the TACSTACK is a Simulcasting multiband radio repeater that allows public safety departments across the Commonwealth of Massachusetts to communicate during emergencies seamlessly regardless of the radio equipment being used. That is, any public safety official on any radio system can communicate with any other public safety official on any other radio system. The TACSTACK will be capable of supporting all systems from low band VHF analog radios to 800MHz digital trunked Simulcasting networks.

Background Radio Information

In order to understand how to use the PSIC and what its strengths and limitations are, some basic background knowledge about radio systems is necessary. This section covers the basic components of a radio, duplexing, repeaters, trunking, simulcasting, digital networks, and frequency allocation.

Basic Components

All radios contain at least three basic components: a transmitter, receiver, and antenna. Generally all radios will also include a speaker and microphone with push to talk (PTT) capabilities. The Transmitter generally works in three stages. First, it modulates an input signal using either Amplitude Modulation (AM) or Frequency Modulation (FM). AM is rarely used in modern radio communications, so for the purposes of this document, the reader may always assume FM operation. FM works by varying the frequency of a carrier wave across either a 25 kHz or 12.5 kHz (or more recently, 6.25 kHz) range, while keeping relatively constant amplitude. Generally the center of the 25/12.5 kHz range is the frequency noted for transmission. That is, a radio will be programmed for 33 MHz, but will actually be transmitting plus or minus 12.5 kHz around that given a 25 kHz bandwidth is chosen. Once the signal is modulated, it is upconverted to the desired frequency. For the purposes of public safety, this will be anywhere between 30 and 800 MHz (common public safety frequencies will be discussed in further detail later in this section). Once the signal is converted to the proper frequency, it is still extremely weak and not ready for transmission. The final stage of the transmitter is amplification. An amplifier simply takes the small modulated, upconverted signal and outputs it at 5 to over 100 Watts depending on the size of the amplifier. At this point, the transmitter is ready to be plugged into an antenna, which will broadcast the signal over the air.

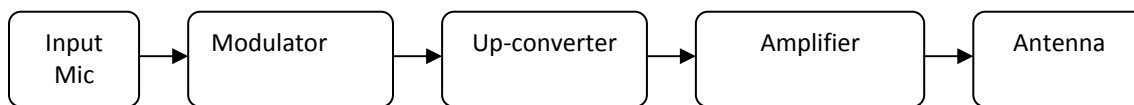


Figure 1: Basic Transmitter Components

The receiver works in essentially the opposite fashion as the transmitter. It also works in three stages, the first of which is a tuner, which allows the receiver to listen on one specific frequency. Next, the signal is demodulated into a simple audio signal, ideally identical to the one put into the transmitter. Finally, that signal is amplified to a point that it is audible to the person listening on the receiving end.

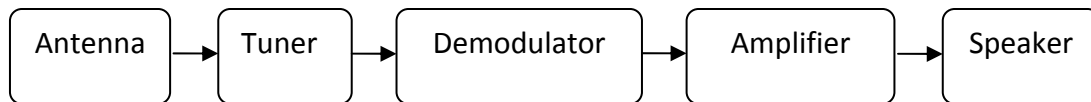


Figure 2: Basic Receiver Components

Duplexing

There are essentially two basic forms of radio communication. The first is simplex communication: one directional communication between a transmitter and receiver. That is, only one transmission can take place at a time. This is the configuration that the PSIC is currently using. The second form is full duplex, where two way transmissions can happen simultaneously. In order to achieve full duplex functionality, two conditions must be met. First of all, there must be specific independent transmit and receive frequencies. In order for a radio to be able to transmit and receive on different frequencies at the same time with one antenna, a duplexer is required. In its most basic form a duplexer is a set of finely tuned filters that only allow the appropriate frequencies to reach the transmitter and receiver. Without this, situations could arise where 50 Watts of power are sent into a transmitter, which would generally break it. Despite the theoretical advantages of a full duplexed system, the vast majority of handheld radios can still only either transmit or receive at a given time.

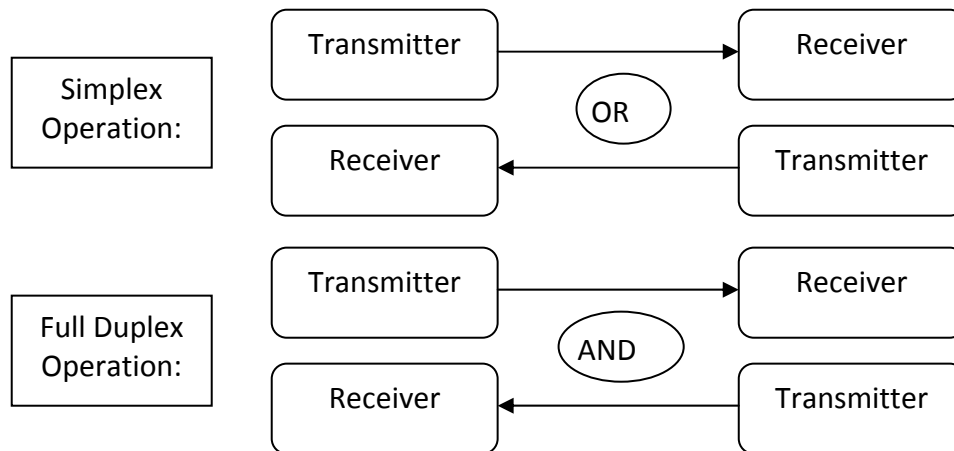


Figure 3: Basic Radio Operating Modes

Repeaters vs. Base Stations

At the core of any large scale radio network is either a base station or repeater. A base station functions mostly as a normal portable radio would, but is more reliable, powerful, and generally able to interface with a wider range of equipment. It is capable only of half duplex operation unless it is used in conjunction with a second base station. Figure 4 illustrates how base station based networks work. The lightning bolts represent the possible range of the radio transmitting (in this case, Mobile Unit 1).

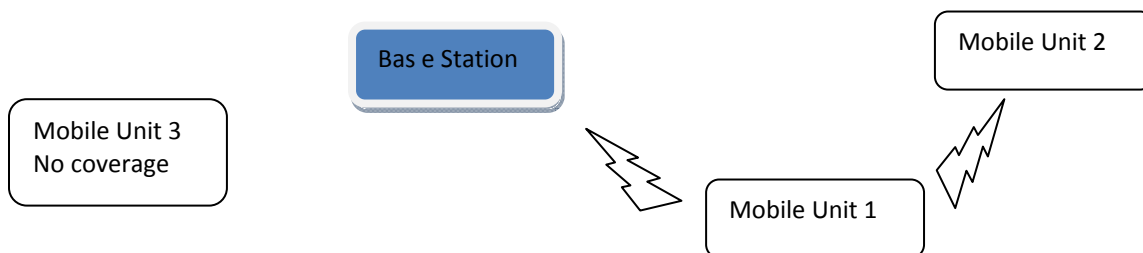


Figure 4: Basic Base Station Architecture

Contrary to a base station, a repeater creates a much larger RF coverage area by repeating all signals sent to it by mobile radios. That is, as long as a radio is in range of the repeater, it can transmit to any other radio in range of the repeater. Figure 5 illustrates basic repeater operation. Observe that Mobile Unit 1 can now easily transmit to Mobile Unit 3 because the repeater has taken the message received from Mobile Unit 1 and has rebroadcasted it. Because the repeater can transmit at a much higher power, this extends the overall range of the network greatly.

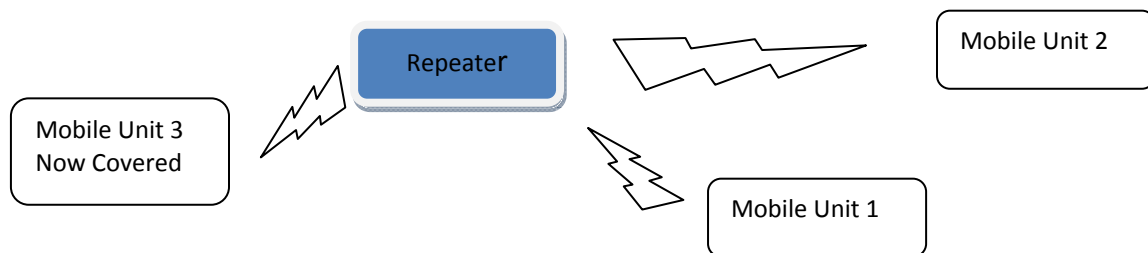


Figure 5: Repeater Architecture

Another form of repeater is a cross band repeater. A cross band repeater functions similarly to a normal repeater, but it repeats all signals it receives over several frequency bands. A cross band repeater could be used to link a VHF and UHF frequency together, for example. Crossband repeating over as large a range of frequencies as possible is a major long-term goal of the PSIC.

Radio Frequency Basics

Most public safety radio systems utilize frequencies on one (or several) of 4 bands: VHF low (25-50MHz), VHF high (138-174MHz), UHF (408-512MHz), or 800MHz. Older systems tend to be VHF based, while newer ones are usually either UHF or 800MHz. Despite general conventions, each band has distinct advantages and disadvantages.

The general equation for radio propagation loss is (in dB) $20 \cdot \log(4\pi d/\lambda)$, where d is the distance in meters and λ is the wavelength in meters. From this equation, one will find that as frequency increases, path loss increases. Therefore, in theory VHF bands have a much higher range than UHF and 800MHz frequencies. This equation only considers propagation in free space unfortunately, and ignores a huge multitude of variables in the real world. Despite its

inherent flaws, it does show that using higher frequencies over large, sprawling areas is not very practical. Some large public safety organizations are attempting to implement large-scale 800MHz systems, which is the sort of thing the PSIC would attempt to discourage with the education of public safety officials.

Some of the other factors influencing radio propagation include terrestrial features and man made objects such as buildings. Both of these are much more difficult to calculate propagation for, but some general rules of thumb can easily be followed. VHF frequencies tend to propagate well over large undeveloped areas, but are poor at penetrating buildings. As frequency increases, building penetration improves. Terrestrial propagation obstacles can be calculated relatively easily with the use of simulation software such as Radio Mobile. Radio Mobile is based on the commonly used Longley Rice model for radio propagation. This model was developed in the 1960s when less scientific methods were generally used for radio infrastructure planning. The Longley Rice model (or Irregular Terrain Model, as it is also commonly known) was a huge advance in radio science. Originally, the model was built in FORTAN, was relatively difficult to use and was not commonly available. Despite the huge advances in easily accessible propagation modeling software today, there are yet still more (more complex) factors that influence propagation that require huge amounts of data.

Simulcasting

For certain applications, the coverage offered by a single repeater is not adequate. In such applications, multiple repeaters must be used across a wide area. Unfortunately, this can not be done as easily as it initially seems. Special equipment is required to make sure that the signal is synchronized properly across the multiple repeaters. This process of properly sending the same signal across multiple remote repeaters is called simulcasting (**simultaneous broadcasting**). When the same signal is broadcast on the same frequency from two locations, the transmission overlap area will usually be completely distorted and unintelligible. This is caused by several factors. First, the carrier frequency of the multiple repeaters is generally slightly off due to minute hardware differences. For similar reasons, the modulation of the

signals is also off slightly. Finally, there is a significant audio delay between the signals. Often, GPS based simulcasting equipment is used to dynamically calculate the appropriate delays.

Voting

Another major problem with simulcast networks is that multiple tower sites may receive the same signal at different strengths and amounts of distortion. When both of these towers send the voice data back to the dispatch center at the same time, a method must be in place to decide which signal to rebroadcast. In this situation, a device known as a voter is used to determine which signal received is the strongest. Both centralized and distributed voting systems exist currently. In a centralized voting system, one piece of voting hardware is located in the dispatch center which controls the entire network. This has several disadvantages, as it allows for a single point of failure in the network and is also not the most effective way to vote. A distributed system is more difficult and expensive to setup, but is more effective and highly redundant.

Trunking

On large radio networks there is too high a volume of traffic for effective communication on a single frequency. The most common way to circumvent this problem is by implementing a trunked system. The goal of trunking is to dynamically distribute radio traffic over a range of frequencies. The implementation for accomplishing this varies, but most systems work in the same general way. There is generally a control channel that all radios on the network always listen to. The control channel contains instructions telling the radios which frequency they need to listen on depending on which talk groups they are programmed for. Talk groups are dynamic radio channels for specific topics of communication. For example, there may be talk groups for particular sections of a city for police or fire use. Only radios that are compatible with particular trunking protocols can be effectively used on a trunked network. Conventional radios can be patched in on fixed channels, but the system is for the most part not very interoperable. Some of the most widely used trunking systems include Motorola Smartzone and EDACS (Enhanced Digital Access Communication System).

P25 Digital Networks

Conventional radio systems rely on analog signals. Analog has many limitations, but is very simple to set up and works with almost any radio currently in service. It is not capable of significant data transmission and is not ideal for distributing large amounts of traffic. Digital networks are highly scalable and support advanced data transfer features, but require compatible hardware and strict adherence to standards in order to offer any interoperability.

The most common digital radio standard in the United States is P25 (Project 25), which is a completely open architecture. It was produced by the Association of Public Safety Communications Officials International (APCO), the National Association of State Telecommunications Directors (NASTD), select Federal Agencies, and the Telecommunications Industry Association (TIA). P25 systems are fully interoperable with conventional analog systems, but primarily operate in digital mode. In digital mode, the analog audio is converted into digital packets via an IBME (Improved Multi-Band Excitation) vocoder. The vocoder is a finely tuned algorithm designed to digitize human voice in a compact and efficient manner, but is able to decode the signal in such a way to maximize vocal understandability. Because the signal is being heavily compressed and expanded again, a large amount of sound quality is lost, greatening the importance of a well designed vocoder. Many public safety officials dislike the way digital vocoders make voices sound because they flatten and deaden them. Because the vocoder is so specifically designed for the human voice using western languages, other signals such as tones and sometimes extremely obscure, foreign sounding language are often badly distorted. These limitations are relatively minor and in recent years have become less of a problem as technology improves.¹

P25 systems use what is called the Common Air Interface (CAI) at 9.6kpps to specify the type and content of signals transmitted. CAI is completely standardized and is the most important part of P25 interoperability. It allows any two P25 radios regardless of hardware or manufacturer to communicate seamlessly. The CAI includes the IBME vocoder conversion,

¹ (Daniels Electric, 2007)pp. 1-12

extensive error correction to prevent data loss over the air, encryption when desired, and unit identification.²

² (Daniels Electric, 2007) p. 17

PSIC Equipment

The PSIC already includes many of the basic components mentioned in the previous section. Currently, it is capable of acting as either a base station or repeater and can handle trunking hardware, although none is currently available. It also is capable of functioning as a quasi-standards compliant P25 digital network via Motorola's ASTRO protocol. Ultimately, the PSIC will include trunking, simulcasting, and voting equipment to simulate any real world radio environment.

Quantar

The Motorola Quantar (Figure 6) currently serves as the main base station for the PSIC. These base stations are capable of transmitting traditional analog and digital signals and may be used with a Motorola trunking system such as SmartZone. When used in conjunction, the two base stations may be used as a full duplex repeater.

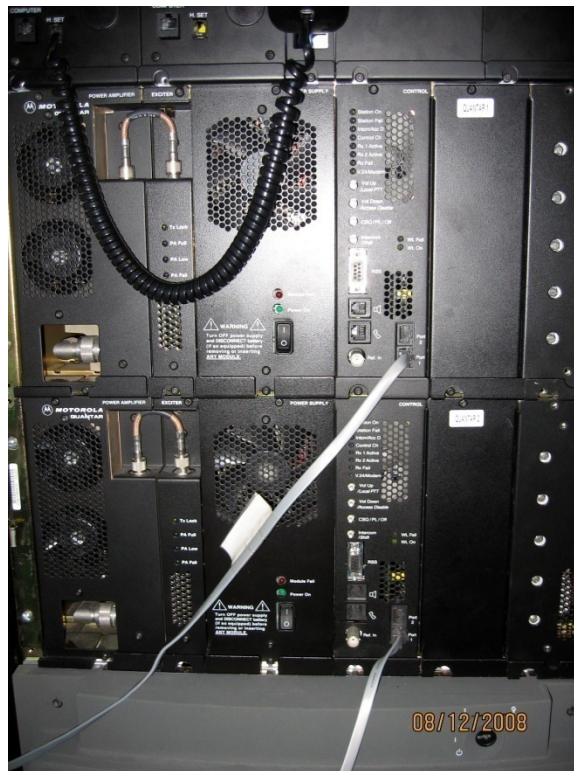


Figure 6: Two Motorola Quantar Base Stations

Usage and Programming

The Quantar can be programmed via the RSS serial port on the front of the unit with the corresponding RSS software which is loaded on the Centracom Elite Server. It requires a null modem cable to program. The RSS software is relatively simple to use for basic features, but the manual, which describes the more advanced features is available in the PSIC.

When being programmed, it is a good idea to disable the unit from transmitting. To do this, one must push the buttons labeled Intercom/Shift button and Vol Down/Access Disable at the same time.³

DIU 3000

The DIU 3000 digital interface unit (Figure 7) is designed to allow easy migration from analog systems to digital systems and is the controller for the Quantar. It responds to standard Motorola function tones, allowing systems such as the Centracom Gold Series dispatching consoles to communicate over digital networks. It is also capable of intelligently transmitting either analog or digital signals, allowing compatibility between different radio equipment on the same general network. This is especially useful to the PSIC because it allows the Quantar to seamlessly communicate over both analog and digital mediums.⁴

³ (Motorola, Inc.)

⁴ (Motorola, Inc., 2001)



Figure 7: Two DIU 3000s

Usage and Programming

The DIU's onboard interface allows the user to pick a channel to transmit on via the attached handset. Aside from this, the interface has limited usefulness for the purposes of the PSIC.

Programming the unit is similar to that of the Quantar. The software is also available on the Centracom Elite Server and requires a special RJ-45 to DB-9 cable that plugs into the RJ-45 COMPUTER port on the front of the unit. The cable uses a proprietary Motorola pin-out.

Additionally, encryption keys can be loaded into the DIU via a small port on the front of the unit underneath a small circular plastic cover.

Centracom Gold

Motorola's Centracom Gold series is a powerful dispatch center capable of handling a multitude of different incoming data sources. With this station, the PSIC is capable of receiving and transmitting on many different radio channels (be it analog or digital; encrypted or unencrypted), phones, or almost any other voice or data source. The Centracom Gold is made up of several parts. First is the power supply, second are the card cages, also known as Central Electronics Banks (CEBs), which contain most of the processing power of the system, and third are the console interface electronics units (CIEs,) which act as a bridge between the Centracom

and the dispatch PCs. The entire system aside from the dispatcher boxes at the actual dispatch station is powered by the unit shown in Figure 8. This power supply also supports battery backup power, but no batteries are currently connected.



Figure 8: Centracom Gold Power Supply

Card Cages

The PSIC Centracom Gold contains three card cages. Two of these cages are backed with a CEB Interconnect Board. The interconnect board can hold up to 10 CEB modules (numbered from 1 to 10 from left to right) and 10 smaller option boards. It provides power and signal busing to all modules as well as a connection to telephone lines via the included punch block. The center two slots (5 and 6) interface with the operator position while the other slots interface with external equipment and phone lines. On the bottom of each interconnect board is a port that connects to other card cages so additional cards can be added either for extra features or redundancy. Figure 9 illustrates a typical card cage configuration.

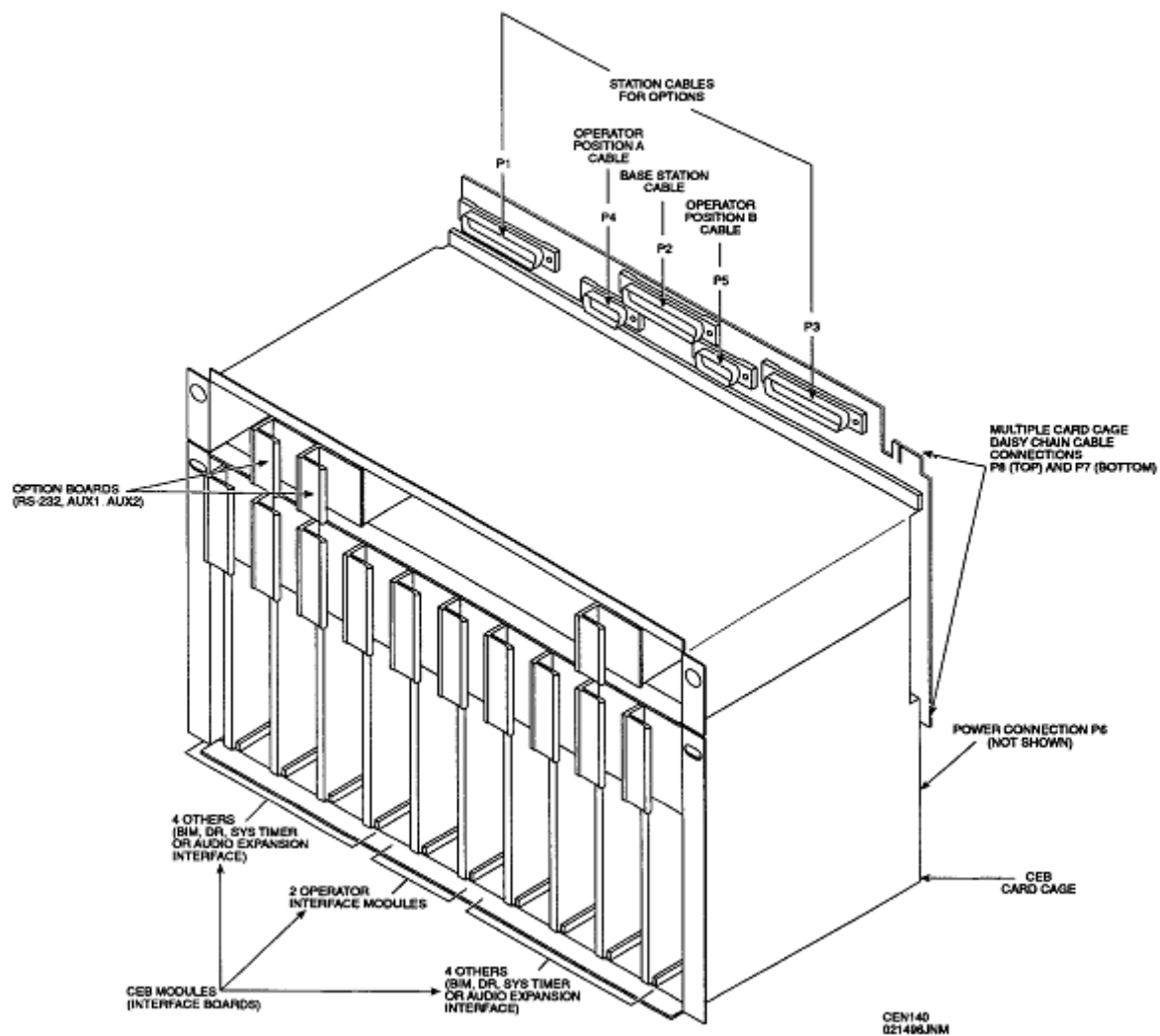


Figure 9: Card Cage Diagram⁵

The Centracom Gold card cages in the PSIC contain the following types of cards:

1. BLN1228A Main Board: Provides an interface between the Central Electronics Bank and the CIE, and the PC (Elite Server). The Main Board PROM (BVN6052A) is reprogrammable for device addressing purposes via the Console Database Manager found on the Elite Server. Two main boards are currently installed in the PSIC's Centracom system for the purpose of redundancy.⁶

⁵ (Motorola, Inc., 2001) Chapter 3, p. 16

⁶ (Motorola, Inc., 2000)

2. BLN7011A System Timer Module: Generates a main system clock and frame synchronization signal, which synchronizes all Central Electronics Bank time division multiplex bus communication. It also generates a clock signal used in automatic level control circuits of CEB modules, arbitrates system data bus usage, generates a 10Hz real time clock time base, and generates a guard tone signal for use in keying a base station. Similarly to the Main Board, two of these cards are supplied for redundancy.⁷
3. BLN6654D Base Interface Module: Receives analog audio from the base station, digitizes it, and sends it to operator positions in the system. Conversely, it also receives digital audio from operator positions, converts it to analog, and sends it to the base station. It also is capable of generating tones and DC levels to control the base station, and sends data to operator positions to acknowledge commands and to report its status.⁸
4. BLN6664B Auxiliary I Module (Aux I): Located directly above the BIM, the Aux I module contains relays used to control external devices or employ various 2 or 4-wire options. Works in direct conjunction with a Base Interface Module.⁹
5. BLN1215A ASTRO Console Interface Module (ACIM): Adds an ASTRO data signaling option to the BIM, which is used for functions such as providing PDD IDs, selective calling, and status messages. The BIM tells the ACIM what data to send, and the ACIM converts that data to ASTRO, which is then send to the DIU. These cards do not need to actually connect to the card cage. They simply sit inside the card cage and interface with other cards via the ribbon cable port on top of them.¹⁰
6. B1441A Phone Patch BIM: Behaves very similarly to the BLN6654D BIM, but instead of interfacing with a base station, interfaces with a common phone line.

⁷ (Motorola, Inc., 2000)

⁸ (Motorola, Inc., 2000)

⁹ (Motorola, Inc., 2000)

¹⁰ (Motorola, Inc., 2000)

7. B1840A Base Interface Module: Little is known about this card. It appears to be another phone patch module, but is designed for larger Telco systems, as it seems to connect to the punch block included with the system.

Card cage 2 (Figure 10) holds the majority of the cards in the PSIC's Centracom Gold. It contains (respectively from left to right) two BIMs, the B1840A, the phone patch BIM, a main board, another BIM and ACIM card (which interfaces with the Nextel radio), and a system timer.

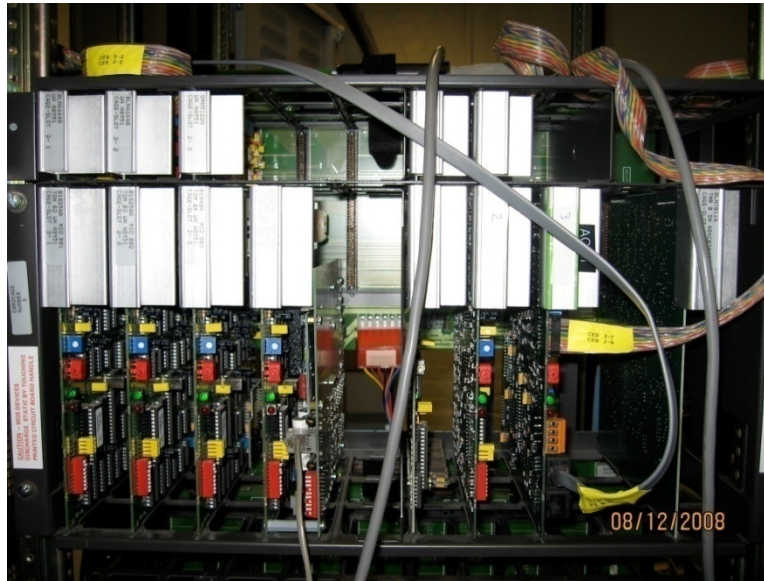


Figure 10: Centracom Card cage 2

Card cage 1 (Figure 11) contains only a redundant main board and system timer.



Figure 11: Centracom Card cage 1

Card cage 3 (shown in Figure 14, also containing the Nextel radio) contains only two ACIMs and thus does not require a CEB Interconnect Board. The ACIM cards it contains interface with the two DIUs and the first two BIMs in card cage 2.

More information about the configuration and of the card cages can be found in the Assembly segment of this document.

Centracom Elite Server

The Centracom Elite server hosts the actual dispatching interface for the Centracom Gold. The Elite Dispatch software provides a graphical interface for all of the features mentioned in the Centracom Gold description.

The Elite Dispatch suite is made up of the following pieces of software

Elite Dispatch

Elite Dispatch is the main Centracom dispatching software. It allows transmitting and receiving from many different sources in one centralized location. It also allows an individual to patch different sources together.

Elite Admin

Elite Admin allows a user to edit the interface in Elite Dispatch. It pulls all of its data about available components from the Console Database Manager and Alias Database Manager.

Console Database Manager (CDM)

The Console Database Manager contains all of the data regarding the cards currently configured in the Centracom card cages. It contains addressing information, maintains a list of enabled features, and allows labeling of the components. It also includes a feature to reprogram the Centracom cards.

Alias Database Manager

This software contains data that defines how the hardware configured in the CDM is displayed in the Elite Dispatch Software.

As previously mentioned, this computer also hosts the programming software for the Quantar base stations and DIU 3000s.



Figure 12: Elite Server

NOTE: The Administrator password for the server (which is required to login) is psic123x.

CAD Servers

In addition to the Elite server, the PSIC also includes 3 Computer Aided Dispatch (CAD) servers. These three machines host a range of dispatch related software that would be critical in a real dispatching environment. All three machines include Intergraph Public Safety software, which can handle such tasks as dispatch log management and statistical analysis. Some of the Intergraph software includes geolocation applications so that a dispatcher could input an address and pinpoint on a map where an emergency is for either statistical or immediate dispatching purposes.

Currently, none of the CAD software is currently working properly due to drastically different networking structures between the PSIC and SAIC as well as what appear to be corrupted software installs. The PSIC also only has install files for a limited amount of software, making it currently irreparable.



Figure 13: CAD Servers

NOTE: The Administrator password for the servers (which is required to login) is cad911.

Nextel Radio

The PSIC includes a Nextel mobile radio, which is theoretically similar in function to any consumer grade push to talk Nextel radio. Unfortunately, this piece of equipment predates Nextel's ability to use its push to talk service nationwide, so it will only work in its original location (in northern Virginia). For the purposes of the PSIC, it serves as an excellent example

of how to patch nonstandard components into the Centracom Gold dispatch center. The Nextel currently uses the same type of card as the DIU's to interface with the Centracom, that is, a BIM in conjunction with an ACIM. This interface is made possible by the small black box next to the Nextel radio in Figure 14.



Figure 14: Nextel Radio

Radio Network Controller (RNC)

The RNC (Figure 15) provides an interface between RF networks and at least one host computer. It controls the flow of data transmissions between mobile and portable terminals and modems and the fixed host computers. It connects over a TCP/IP network, so using it with other computers is relatively simple. It can handle tasks such as formatting messages for transmission between the RNC and devices using Motorola Data Communications (MDC), selecting which base sites should transmit outbound messages, monitoring the status of Base Station Controllers and report alarms, collecting statistics, running diagnostics, and encrypting data messages.¹¹

¹¹ (Motorola, Inc., 1998)



Figure 15: Radio Network Controller (RNC)

Encryption

The RNC supports encryption via a SCSI interface with up to six encryption boxes. Two of these small boxes (currently on top of the WNG) are independently powered via IEC cables and are connected to the RNC by daisy chaining them together and addressing them via the small numerical display on their back.

Wireless Network Gateway (WNG)

The WNG (Figure 16) essentially acts as the routing component of a Motorola data communications network. It connects wireline networks and RF data networks, allowing the RNC to send its data messages to devices as though they were all on the same network. It provides all of the routing, translation, fragmentation, and error notification services needed to make that happen.¹²

¹² (Motorola, Inc., 1999)



Figure 16: Wireless Network Gateway (WNG)

The WNG, which runs the AIX operating system, is functionally the same as most UNIX based servers. It contains a folder full of software specific to the WNG, but is otherwise administered the same as any Unix server.

Dummy Load

All of the PSIC radio equipment is currently transmitting through dummy loads. The particular dummy loads that we are using are solid state devices that handle up to 300W transmissions. They follow the deration curve shown on the front of the unit.

Motorola Spectra

These mobile radios (Figure 17) are capable of receiving both analog and ASTRO encrypted or unencrypted digital signals. These particular models support VHF high band frequencies.



Figure 17: Motorola Spectra Radio

In addition to voice, these radios are capable of basic data functions such as emergency alerts, addressing, and over the air rekeying (OTAR).

Ross DSC500

Little is known about these rather old radios (Figure 18) except that they operate on VHF hi-band marine frequencies. They appear to have been built in the late 1980s by a company that either no longer exists or has changed names. No documentation has been located, making these radios impossible to reprogram for the purposes of the PSIC. This will render these radios useless when the PSIC becomes licensed to transmit on new frequencies.



Figure 18: Ross DSC500 Radio

AEA PK-12 Packet Modem

These modems were the first pieces of equipment to be added to the PSIC during its time at WPI. These modems were formerly used as part of a different MQP at WPI and most of the documentation we have for them comes from that MQP.

These modems connect to a computer via a straight through (not null modem) serial cable (DB25 to DB9) and to a radio via a custom cable. Two custom cables currently exist; one for interfacing with an RNET 450S (see below) and one for interfacing with an M-10. The M-10 is not yet used in the PSIC, however what documentation we have regarding it, including the cable pin out is attached in Appendix B: PK-12 Packet Modem and RNET 450s Information Continued.

Communication with the modems from a computer is established through a program capable of serial communication such as telnet or putty. Details about the syntax of interfacing with these radios can be found in Appendix A: PK-12 Packet Modem and RNET 450s Information and Appendix B: PK-12 Packet Modem and RNET 450s Information Continued.

Overall this information is very accurate. Several of these radios are currently configured to run at a baud rate other than the default 9600 baud. This simply means several baud rates may need to be tried before communication can be established.



Figure 19: AEA PK-12 Packet Modem (Front)

At present, the PK-12s have only been able to talk to one another outside of integration with the PSIC. Having demonstrated their functionality, the next step would be to complete integration with the PSIC dispatch center in such a way that their transmissions could be routed to any radio in the system. Having established their input and output methods this is now blocked by our limited knowledge of the Centracom system and our ability to add new systems to it. However, we were able to successfully witness the receive light illuminate by connecting an audio output from the Centracom to the green wire (pin 4) and the brown wire (pin 2) and using the procedure outlined in Appendix A: PK-12 Packet Modem and RNET 450s Information and Appendix B: PK-12 Packet Modem and RNET 450s Information Continued.

Motorola RNET 450S Data Radio

The RNET 450S is a 2 watt UHF transceiver (supports both transmit and receive functionality) at 452MHz. It is a small form factor radio that simply accepts a push to talk signal, audio in and audio out provided by the data radio and modulates and amplifies it out to an external antenna. When used in conjunction with the AEA PK-12 these radios provide a wireless serial link between two computers.

The pinout for this radio can be found in Appendix A: PK-12 Packet Modem and RNET 450s Information and Appendix B: PK-12 Packet Modem and RNET 450s Information Continued. Also note that 12V DC is needed to power this radio. Many of the PK-12 modems have been modified at some point to provide 12V DC output to a 1/4" connector. Combining this power connector with the PK-12 radio connection and the RNET data connection yields the cable shown in Figure 20. The leftmost connector plugs into the RNET 450S and the remaining two connect to the PK-12.



Figure 20: Data + Power Connection

Unfortunately this is not the same frequency as the rest of the system is currently configured to use; making this radio of limited usefulness to the PSIC. However, the simplicity of this radio makes it an excellent candidate for hardwired integration with the PSIC. The current barrier to this integration is the lack of push to talk output from the Centracom system to tell the RNET that it should begin transmitting. Once this radio is integrated it would demonstrate the ability to add additional devices and frequencies to the PSIC dispatch center.



Figure 21: RNET 450S

Custom Cables

In order to determine how the system works we needed a way of probing the signals between various pieces of equipment. Throughout the system various cables are used, many of which we could directly probe with an oscilloscope, however some were not easily probed. The most difficult to probe were RJ-45 “Cat-5” cables. Additionally, we could not observe the proper behavior of the system with the cables unplugged. To get around this problem we created several custom cables. The first of these custom cables was simply an Ethernet cable that we cut open to reveal each of the conductors. This allowed us to attach probes and alternative inputs and outputs to whichever inputs/outputs the Ethernet cable was connecting.

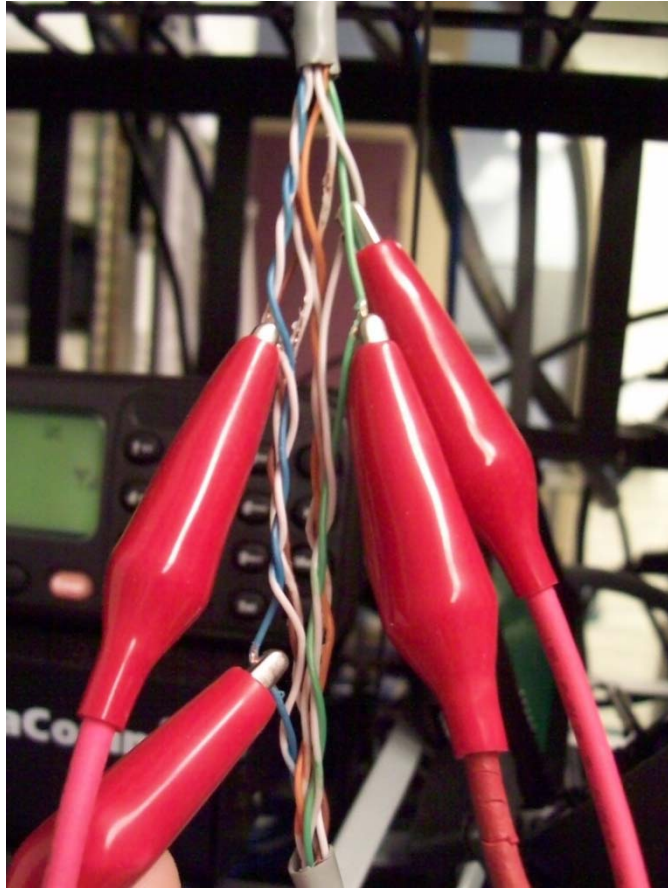


Figure 22: F-F Patch Cable

The correspondence between the pins on the Ethernet connector and wires exposed is shown in

Table 1.



Table 1: F-F Ethernet Cable Pin Out

Pin	Wire
1	White Green
2	Green
3	White Orange
4	Blue

5	White Blue
6	Orange
7	White Brown
8	Brown

This cable was useful in many situations; however it was not useful when analyzing a cable that had RJ-45 on one end and some other connector on the other end. To attempt to determine what may be traveling over these connections we also created a cable that could be patched in line with anything having an Ethernet connector on one end. This cable is shown in Figure 23.

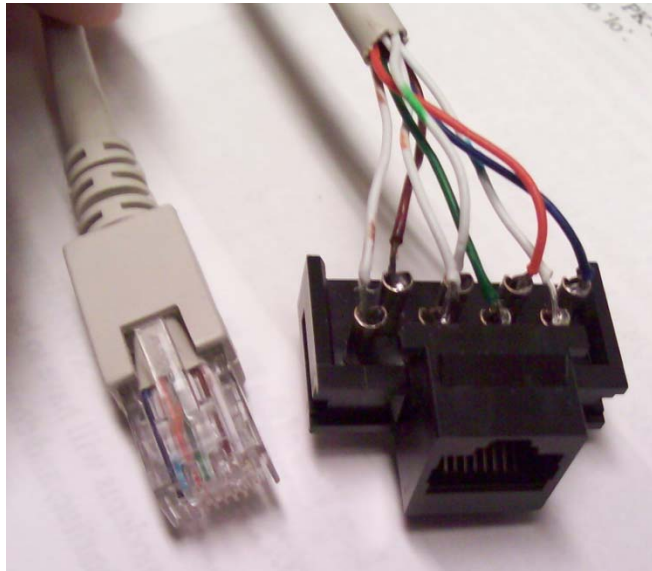


Figure 23: M-F Patch Cable

The extra large terminals on the back of the female connector are conveniently laid out in the same order as the pins in the connector.

PSIC Assembly

The assembly stage of this project was greatly aided by the fact that much of the equipment sent from SAIC was well labeled. Unfortunately, there was very little documentation included with the equipment meaning once it was all hooked together, we had no further information. We knew so little that we couldn't even tell if it was working properly once it was all hooked together and turned on. Gradually, we were able to figure out what each component did, how to use them properly, and how to reconfigure them. By the end of this process we had assembled the majority of PSIC equipment as described below.

Rack Layout

The PSIC is made up of two racks. The first rack contains all of the RF equipment and some overflow dispatch and network equipment, while the second is entirely dispatch and network equipment. Rack 1 contains both Quantar base stations, both DIU-3000s, the Radio Network Controller (RNC), the third Centracom card cage, and the card cage patch bay. Rack 2 contains two Centracom card cages, the Centracom power supply, and the Wireless Network Gateway (WNG). Figure 24: PSIC Rack Layout illustrates the overall layout of the two racks.

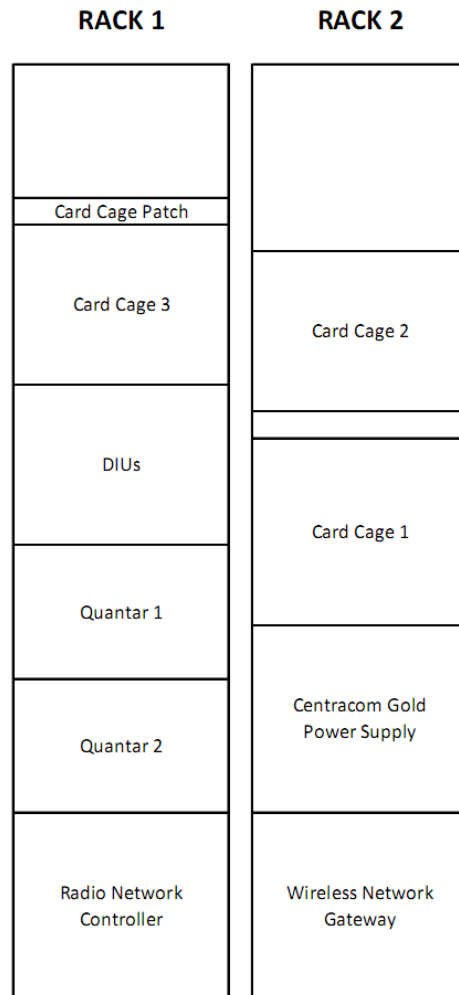


Figure 24: PSIC Rack Layout

Connections

The connections between the various pieces of equipment in the PSIC lab are extensive and complex. It is of the utmost importance to remember that this is primarily a digital system although portions of it contain analog audio pathways. With this in mind, many of the data paths are not obvious even to someone familiar with the system. It may be useful to refer to Figure 26 and Figure 29 while reviewing the following sections as they represent our best understanding of the overall system flow.

Centracom Gold Connections

The layout of the Centracom Gold card cages is shown in Figure 25. The Centracom Gold is capable of taking a multitude of inputs. The two most common ones are RF and phone communications. Ultimately all radio equipment connects to the Centracom Gold Card cages

(labeled CEB, or central electronics bank in Figure 26) via serial cables terminated with RJ-45 connectors. Both DIU-3000s are connected to the Centracom via serial connection to both the ACIM (found in card cage 3, slots 9 & 10) and BIM (found in card cage 2, slots 1 & 2) cards. The ACIM handles all ASTRO encoding, while the BIM handles the conversion necessary to communicate to the rest of the Centracom hardware. The ACIM is connected to an AUX 1 card directly above the BIM with a ribbon cable. The ACIM has an RJ-45 port labeled DIU, which is predictably how the DIU connects. The BIM is indirectly connected via RJ-45 by the patch bay found above the DIUs. This patch bay plugs into card cage 1 via an RJ-21 connector found on the top middle of the CEB Interconnect board (the PCB backing to the card cage). The patch bay is clearly labeled with corresponding card cages and card slots. Simply follow the labeling to make an RJ-45 connection to the desired card. The phone line is connected through the port on the front of the card in cage 2 slot 4. Cage 2 slot 3 is another type of phone card, but it interfaces with a punch block. The Nextel radio is connected to the Centracom in almost the exact same fashion as the DIU.

The dispatch station connects to the Centracom through a serial cable with a proprietary connector. This cable plugs into the leftmost corresponding socket on the CEB Interconnect Board on card cage 2. This socket is connected to the Main Board, which acts as a distribution point for incoming signals. On the other end of the Centracom dispatch connection is one of the CIEs, which is connected via a DB-9 to RJ-45 cable to the Centracom Elite server's serial port. All dispatch control is performed from this server with the Centracom Elite Dispatch Software.

The Centracom Gold is powered by the power supply on rack 2. Each side of the power supply is completely independent and powers a different card rack.

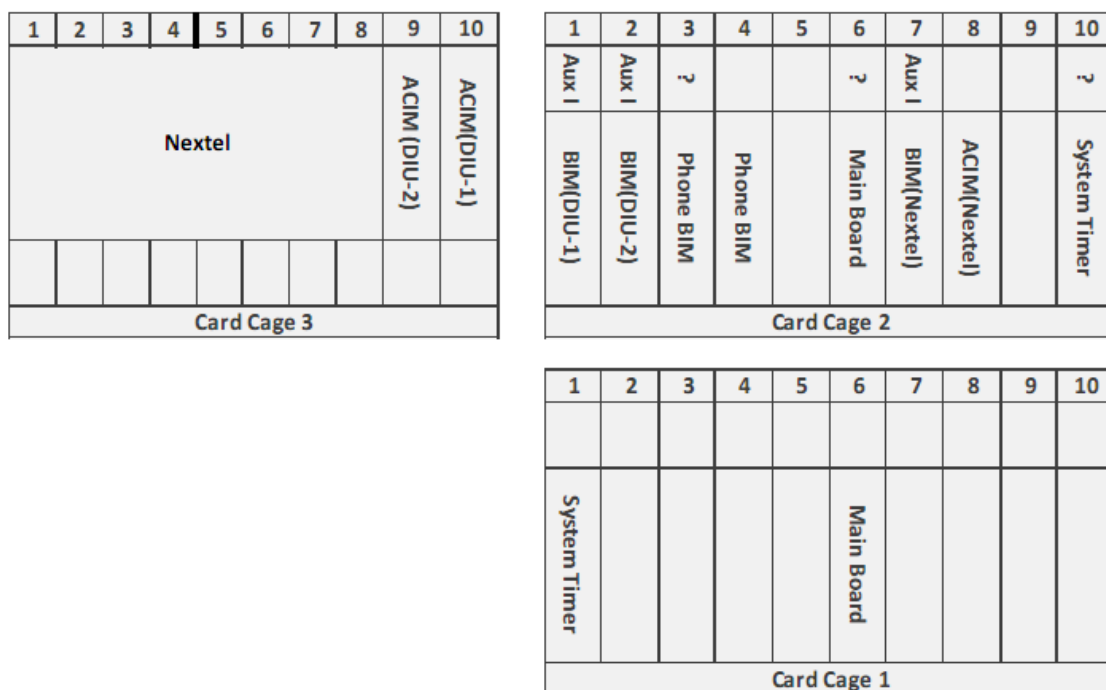


Figure 25: Card Cage Diagram

DIU Connections

The DIU acts as the bridge between the outside RF network and the Dispatch center. It therefore must connect to the base stations, the radio network controller (RNC), and the Centracom Gold. All connections are made via RJ-45 serial connections. The Quantar base stations connect via 'Port 1' on the front of the unit to the NULL port on the back of the DIU. The RNC connects via several RJ-45 to DB-25 adaptors that plug into a multi-channel serial cable splitter that terminate into a single connector that plugs into the SDP12 port on the RNC.

Quantar Connections

The Quantar base stations are connected only to an antenna and the DIU. All it does is transmit and receive with whatever format is sent to it, which is why the DIU is so crucial. It currently connects to a dummy load via a UHF type coaxial connection and to the DIU via Port 17 and Port 1 over RJ-45 serial cables.

Radio Network Controller (RNC) Connections

As previously stated, the RNC connects via a multichannel bus to both DIUs. It also connects via a standard Ethernet cable to a TCP/IP network. The RNC behaves as any other computer would behave on this network, but only sends to and receives data from the wireless network

gateway (WNG). To control the RNC, a DB-25 to DB-9 cable with a null modem pin out connects to a computer (currently the CAD servers) loaded with software capable of VT100 terminal emulation such as PuTTY. The RNC is also capable of encrypting data with the use of the encryption modules labeled CRYPT-1 and CRYPT-2. These modules are connected via a SCSI port on the back of the RNC in a daisy chain formation.

Wireless Network Gateway (WNG) Connections

The WNG connects only to a TCP/IP network. It communicates with both the RNC as well as any number of host computers. Currently, the PSIC contains three computer aided dispatch (CAD) servers capable of serving information to it. Such data hosted the CAD servers could include license plate lookup information or detailed incident logs. The WNG is loaded with a telnet server to allow remote terminal access via the IP network. Additionally, the WNG can also be accessed by terminal software in the exact same manner as the RNC.

Nextel Radio

The Nextel radio (located in card cage 3) is connected to the ACIM and BIM cards on the Centracom Gold via a small box made from what is apparently a Motorola handset cradle. This box takes in a serial cable that comes directly from the back of the Nextel, and outputs two RJ-45 cables. One goes to an ACIM and the other goes to a BIM. The Nextel is powered by a 13.8V power supply directly below it.

Our understanding of the overall flow of data (whether it be digital or analog) through the radio racks is shown in Figure 26. This figure was revised and expanded upon in Figure 29 during the analysis portion of this MQP.

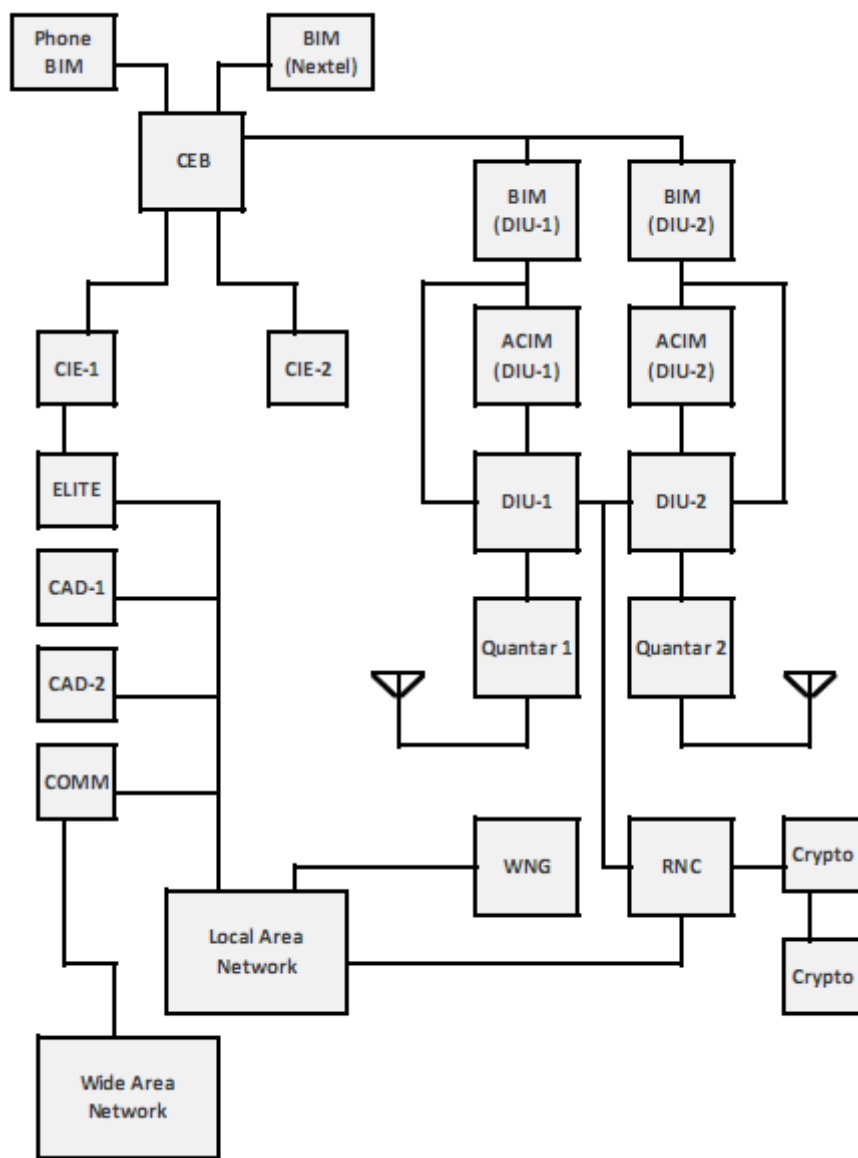


Figure 26: PSIC Connection Diagram

Assembled PSIC Pictures

Figure 27 and Figure 28 are pictures of the current PSIC @ WPI setup. Figure 27 shows all of the communication components with the exception of the physical Centracom Gold units. The Centracom Gold units are the units in Figure 28 below two of the LCD monitors.



Figure 27: Assembled PSIC Racks



Figure 28: PSIC Dispatch console/workspace

Analysis

The analysis stage of this project has been very time consuming and not extremely productive. A lack of manuals and a real understanding of what each part of the equipment was doing led to a situation where extensive trial and error was needed to determine what was truly happening with this system

RNC & WNG

The RNC (Radio Network Controller) and WNG (wireless network gateway) are the brain of the Motorola ASTRO system. They handle all digital radio addressing and message routing and can connect to other ASTRO systems over the Internet. The RNC runs a DOS-like operating system that includes a relatively small set of commands to configure and control the module. The WNG runs the AIX operating system and is essentially a generic Unix server with radio routing software loaded onto it.

When we received the RNC and WNG, we found that they were supposed to be connected to some sort of dumb terminal and keyboard to control them. We received only one terminal and no keyboards from SAIC, which led us to believe that we were missing at least a few critical components. After pondering this dilemma, we attempted to connect the included terminal to both the RNC and WNG to no avail. We were never able to get any sort of meaningful output on the terminal. After much time being stumped by this problem, we hooked up the console ports on the RNC and WNG to the serial ports on the computer aided dispatch servers. To do this, we needed to use DB25 cables connected to DB9 cables via a 25 to 9 pin null modem adapter. To actually view traffic over the serial connections, we ran PuTTY on the CAD servers. We found that to view the output of the RNC and WNG properly, we had to enable VT100 terminal emulation in PuTTY.

With the newfound ability to communicate with the RNC and WNG, we attempted to configure them to the best of our knowledge. Both servers contained configuration applications, which we used to set them up properly on our IP network. After making sure we could successfully

ping the RNC and WNG from the CAD servers over the network, we were sure they were configured correctly.

Unfortunately, the only useful thing we were ever able to make either the RNC or WNG do was log when there was radio traffic. Beyond that, we never got any of the more advanced radio routing features working both because we did not understand how and because it was not particularly relevant to the future of the PSIC. The one feature that would be extremely useful for the PSIC would be to repeat radio traffic over the Internet. This would require another RNC and WNG however, which is not particularly feasible.

Centracom Software

We found that the software loaded on the Centracom Elite server was quite useful for a multitude of reasons. The two most fundamental pieces of software are the Elite Dispatch and Elite Admin applications. Elite Dispatch is the end-user software for dispatching purposes, while Elite Admin can modify the interface of Elite Dispatch. This software, we found, allows the user to add and remove dispatching features that are defined in the Console Database Manager and Alias Database Manager. The CDM is where the majority of the technical specifications reside and has the ability to reprogram the EEPROM on the Centracom Gold Cards. This software is not designed to be utilized to any gain very easily. There is a very definite relationship between the hardware and software in the Centracom Gold system. That is, all changes on the software end must be matched by corresponding changes on the hardware end. The relationship between these is never obvious and is clearly designed to only be workable by Motorola technicians. In order to change most settings, contact points on the Centracom cards must either be shorted together or disconnected by soldering them together or cutting small resistors out of them. Because a huge amount of documentation is needed to figure out how to do this properly, we were never able to get the software to successfully change any settings. Fortunately, there is a wide enough variety of preconfigured cards to suit most of our needs.

External Radios

One of the earliest goals of the PSIC lab is to determine how to add external equipment into the system to facilitate testing of equipment compatibility. The Centracom system is designed to facilitate communication across multiple systems in a dispatch environment, which theoretically should make it easy to add new systems to. However, the Centracom system is designed to work primarily with Motorola equipment and protocols. Additionally, it is designed to be installed and setup by a trained Motorola technician with a full complement of manuals. In our case, we were trying to add non-Motorola equipment, without Motorola training and without manuals.

Despite these challenges we were able to make significant progress. When adding a new piece of equipment several things have to align properly; the software configuration in the dispatch software, the physical hardware configuration (cards and jumpers), the hardware EEPROM settings, and finally the physical device interconnects. The first three of these are very specific to Motorola and without training are very hard to determine.

Fortunately, we temporarily obtained access to some of the manuals for the Centracom system. These manuals described some of the interface cards needed to connect external devices to the Centracom system. Looking at the Nextel radio already connected to the PSIC, we were able to determine that the connections it had to the Centracom system consisted of an analog line in and out connected to a BIM card and a digital line connected to an ACIM card. Probing the connection to the BIM using our custom cables revealed that we could in fact see audio traveling between the Nextel and the Centracom and vice versa.

We then tried adding our own signal to the audio line running into the Centracom to determine if we could cause the Centracom to see this signal as if it were coming in from the Nextel. Unfortunately this did not work. Further investigation revealed that the problem lied in the fact that the Nextel and Centracom were also communicating digitally through the ACIM. It appeared that a special signal had to be sent from the Nextel to the ACIM in order to have the Centracom recognize that a transmission was coming in. Unfortunately, we currently do not have a NEXTEL handheld with which we could initiate a call and analyze the digital signal being

sent. Even then, replicating this digital signal without the reference of a manual is not a small undertaking.

As the digital communication expected by the Centracom appeared to be the stumbling block, we attempted to disable that from the Centracom Software. Again, however, without reference material describing how the software works, we were mostly poking in the dark. We attempted to disable all forms of signaling on the Nextel interface, upload the new EEPROM and try again, but with no luck. In fact, with most of the settings the Nextel interface simply disappeared from the dispatch software. There must be something that was overlooked; however we simply do not know what we were missing.

Stepping back for a moment, we noticed a card in the Centracom card cage that we had not been using. Upon further investigation this card appeared to be the same type of card connecting the Centracom to the analog portion of the Nextel box. We also noticed that this box likely corresponded to a hitherto unused portion of the dispatch software labeled BNTM. A quick change of connections allowed us to patch our external audio source into the send and receive wires of this card and successfully get audio into the dispatch software. We were initially unsure of how this card determined when a transmission was incoming, however after some experimentation we determined that it simply looked for an audio source on the inbound line. With the audio successfully coming into the Centracom software as an incoming transmission, it was easy to use the software to create a patch between the input and whichever output we wanted and vice versa. Doing this, we were able to broadcast an audio signal out of a laptop and to a mobile unit and record a transmission made on a mobile to a laptop.

The overall setup of the system in this configuration is shown in Figure 29: System Overview. Unfortunately, too little is understood about the Centracom software configuration to properly document it besides saying that the current setup works and is backed up as a Norton Ghost image on a spare hard drive in the PSIC lab.

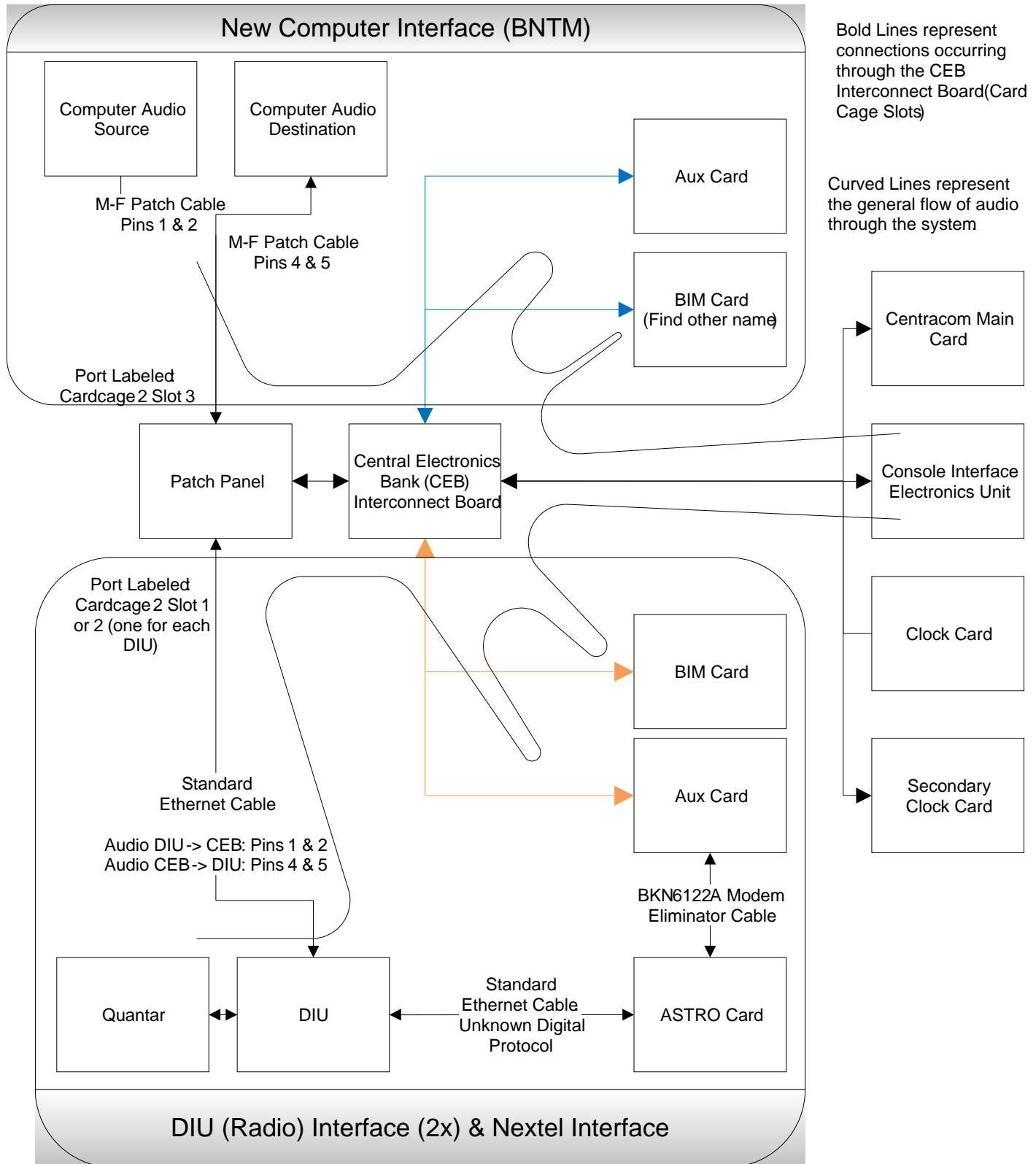


Figure 29: System Overview

TACSTACK Background

In this section, the idea of a TACSTACK is tackled from a theoretical point of view. The TACSTACK is a theoretical concept discussed in Statement of Requirements for Public Safety Wireless Communication and Interoperability by the Department of Homeland Security and Public Safety Communications Interoperability in Maryland by the State of Maryland. These two papers discuss the need for a hardware setup that can allow for multiple agency interoperability to maintain efficient communications channels through disasters and emergencies. There is a lot discussed in these papers but the TACSTACK concept is what will be explored here.

In the traditional simulcast/voting system, all antenna sites report their received signals back to a single point (usually the dispatch center), where a voter decides which signal should be reproduced. Once the decision is made, the highest quality signal is then retransmitted out by each of the repeaters in the system. If there is an overlap concern between repeaters, a simulcast system is most commonly used. The simulcast system has a base station (again usually the dispatch center) and as many slave systems as there are additional antenna sites. While this style of system is tried and true, it is very susceptible to outages. The system has a single point of failure as highlighted in Figure 30.

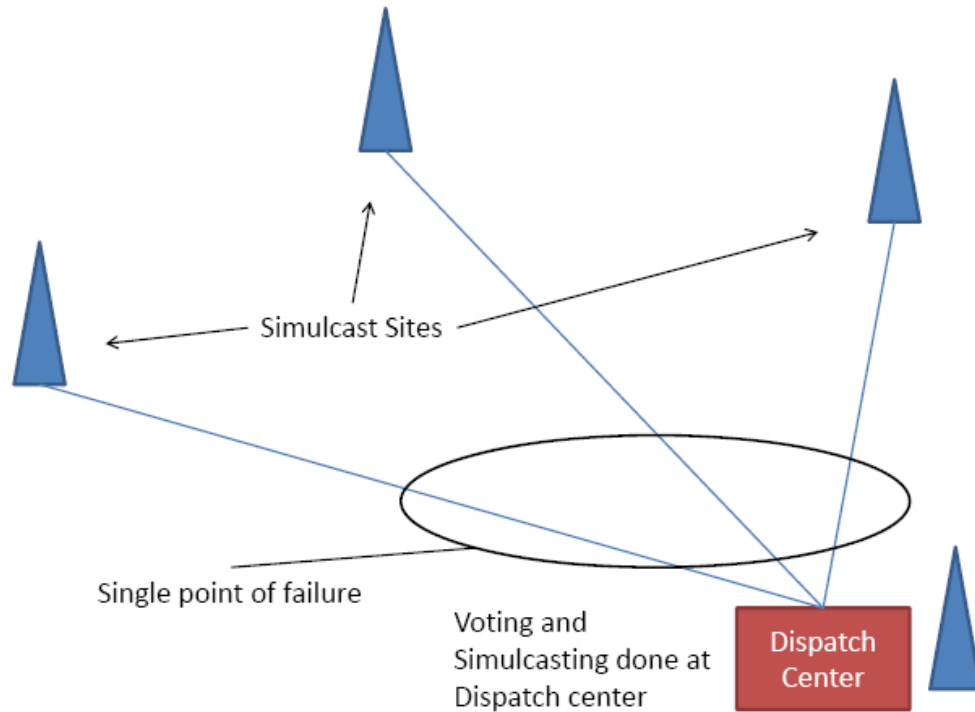


Figure 30 - Traditional simulcast system layout

TACSTACK Objectives

In order for the TACSTACK to be fully interoperable, it must fill three requirements. First, the TACSTACK radio frequency (RF) network must have continuous statewide RF coverage. In order for this to be feasible, each unit must be relatively inexpensive. Second, the network requires full hardware compatibility. That is, any public safety official throughout the state, regardless of radio equipment, must be able to access at least one of the TACSTACK emergency frequencies seamlessly. Third and finally, there must be a continuous network backbone connecting the TACSTACKS. This is probably the most expensive part of the system, as for the most part completely new data links must be installed.

Given these three requirements, a larger, practical list of requirements can be created. For the TACSTACK to be successfully implemented, the following must criterion must be met:

- Statewide RF coverage on bands that all public safety officials have access to (VHF, UHF, 800MHz, etc)

- TACSTACK equipment must be inexpensive
- Equipment must be easy to implement with existing systems
- A high-speed data network must be in place which is accessible by all antenna sites

The following are a list of items that, while not required, are strongly encouraged to ensure the functionality of the TACSTACK system during natural and other large-scale disasters.

- Redundant data links between all TACSTACK antenna sites
- Redundant/backup power sources for all antenna sites

The rest of this section addresses the equipment and infrastructure required to potentially implement such a system. It is important to remember that this is all still in a purely theoretical stage and implementation tests should be completed prior to attempting to implement anything discussed herein.

RF Coverage

Achieving statewide RF coverage is an extremely difficult task that has never been completely achieved in the Commonwealth of Massachusetts before. Because the TACSTACK is fully interoperable with existing equipment, it can be placed in existing radio tower sites. In order to obtain full cross band compatibility, new antennas will need to be placed at most sites, but compared to the cost of building entirely new tower sites this is an extremely efficient solution. Because of the very high number of existing tower sites, relatively few new ones should need to be built.

Most police, fire and emergency services in the Commonwealth are on frequencies divided between VHF, UHF low, UHF high, and 800MHz. Due to this huge spread of used spectrum, there would need to be numerous frequencies in each band dedicated to TACSTACK operation. At least two frequencies would be required in each band, one for traffic to the repeaters (TACSTACKS) and another for the TACSTACK to broadcast out on. Each one of these frequency pairs represents a single channel of voice communication. At a minimum there should be a frequency pair available for police traffic and a pair available for fire/rescue traffic. Since

municipalities don't always have police and fire in the same band, there would potentially need to be frequency pairs in different bands.

The planning process for achieving seamless coverage takes into consideration several factors. First, each band has very different propagation properties. For example, the VHF band frequencies propagate extremely far and thus will require relatively few repeaters. Conversely, 800MHz frequencies have a relatively small propagation radius and behave very strangely in certain environments (such as buildings). Fortunately the Massachusetts State Police already has an 800MHz network that covers a large part of the Commonwealth, making continuous 800MHz coverage an economically feasible option.

Also taken into consideration is the terrain and population density of the Commonwealth. These factors are more difficult to plan for because of the nature of the current radio infrastructure. Towns generally only plan their radio systems to guarantee coverage within their jurisdiction. Because of this, propagation simulations must be run in order to insure that there are no coverage gaps between towns.

Hardware Configuration

The hardware inside the TACSTACK is the heart of the entire system. Without a carefully planned, economically feasible hardware configuration, the system cannot realistically be implemented. Each TACSTACK must be to be customized for the particular location it resides in, so it must be extremely modular. Not every frequency band needs a repeater at every TACSTACK site, which means that the system can cut costs by minimizing hardware.

The TACKSTACK itself must have several key features:

- Ability to transmit on up to 5 bands (VHF Low, VHF High, UHF Low, UHF High, 800MHz)
- Ability to simulcast across a large network via VoIP
- Feature a high level of redundancy
- Be inexpensive enough to place at a large number of sites
- Feature P25 compatibility

System Backbone

In order for the TACSTACK to be proven a truly feasible undertaking, some plan of data transmission between sites must be established. Because it is used almost exclusively in emergencies, the data links must be extremely stable and redundant. Given the options for connecting the sites (running copper, fiber, microwave, or satellite) this becomes an extremely expensive undertaking. Some research must be done as to which types of data links must be run between sites and how much it would cost to implement. Several cost saving ideas include using the already established public internet to transmit data or using cellular networks. Both of these plans are extremely flawed for both security and stability reasons however. They may be useful as redundant backup transmission sources.

In addition to the cost of implementing such a data network, there are severe latency issues that need to be resolved. In order for the network to accurately simulcast signals, they have to all be properly synchronized on the data network. Every medium of transmission will have different latency times, which can be accounted for given some latency data collection.

Unfortunately because the system must be redundant, if one data link goes down the entire latency equations for the system will be altered when alternate data lines kick in. This issue could potentially be avoided by setting a delay on the entire system so that all data is synchronized, but this will only work if the latencies stay within certain reasonable boundaries. In the event of a massive disaster, it is likely that latency time could become totally unpredictable, rendering the entire system nearly unusable.

TACSTACK Execution

System Layout

To realize this large and complicated system, the team brainstormed ways of meeting all of the requirements discussed above. As a result, a system architecture and implementation scheme was devised. The architecture is based on technologies not yet commonplace and focuses on being as redundant and flexible as possible. Just as mentioned before, the ideal solution for connecting antenna sites is believed to be in a mesh network configuration. This mesh network also needs to be a data network. Switching from an analog or voice network is important because it can allow for more traffic between sites and dispatch centers. Data traffic could include weather reports at sites, antenna and hardware statuses, as well as the traditional voice traffic. Since the network would be exclusively digital, all radio communication would need to be digitized at the antenna sites for transmission to other sites to be simulcast, or voted on. Making the entire network digital would allow for the system to be incredibly robust and make it easy to reprogram if problems ever came up. Figure 31 shows a potential configuration of the hardware at each antenna site. The processor and link to the TACSTACK network are designed so that any repeater can be used as long as it has remote control capabilities. Because all hardware would be standardized for all TACSTACKs—at least with regards to the protocols with which it operates on the TACSTACK (MTS-NET) network, hardware dispatch centers only needs to be able to have control over the individual TACSTACKs in their jurisdiction.

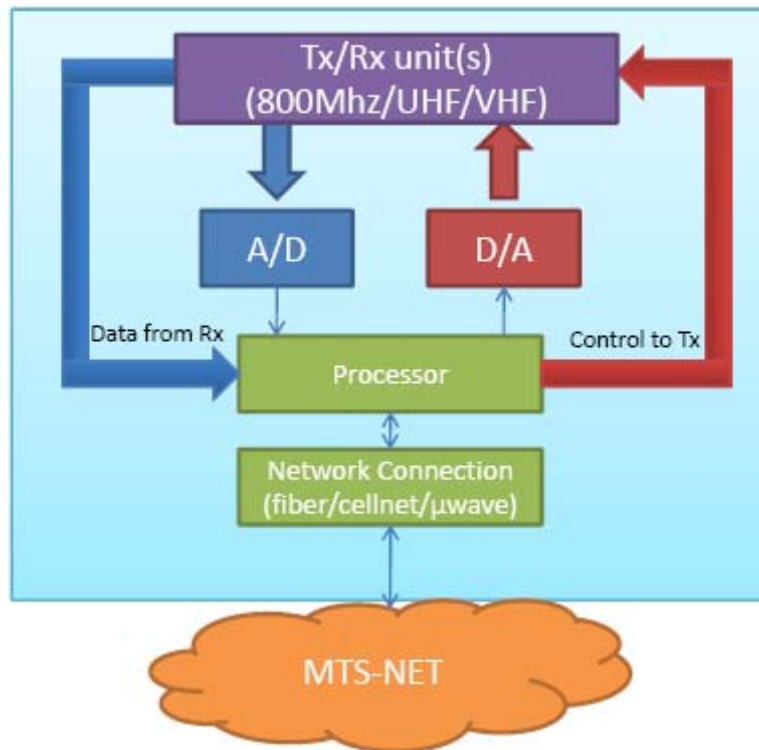


Figure 31 - Antenna site hardware layout

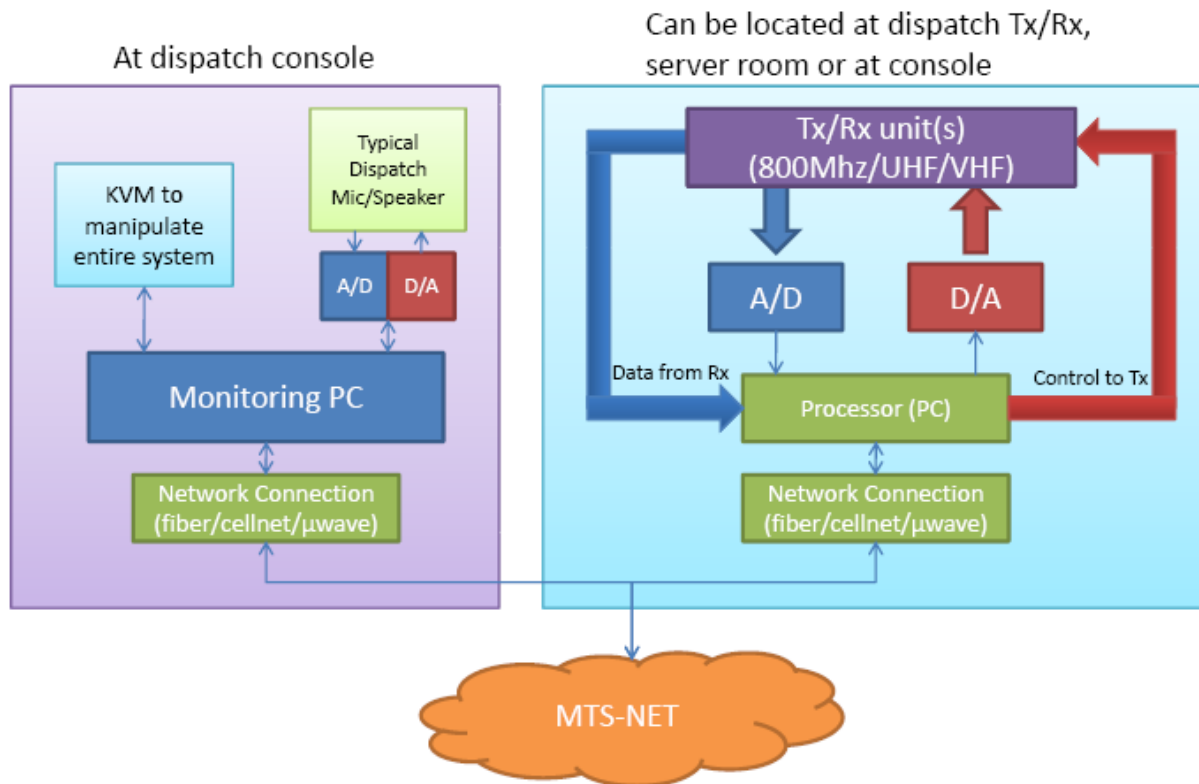


Figure 32 - Dispatch center hardware layout

Another concern with a statewide mesh network is the issue of privacy. In an emergency, multiple agencies may be required to work together and share radio space, but in day-to-day operations municipalities want to keep their antenna sites to themselves and not have to worry about unauthorized use on their frequencies. This problem is tackled by implementing what the team has called “layers”. The idea behind layers is that each municipality/agency/dispatch center is responsible for their own antenna sites/frequencies. In normal operation, a single dispatch center would be maintain distributed voting and simulcasting (where applicable) for its own antenna sites. In the event of an emergency, dispatches would be able to create emergency layers which would change the routing, simulcasting and voting of antenna sites, based on where an emergency was and who was required to respond. An example of a normal layering and an emergency layer can be found in Figure 33 and Figure 34.

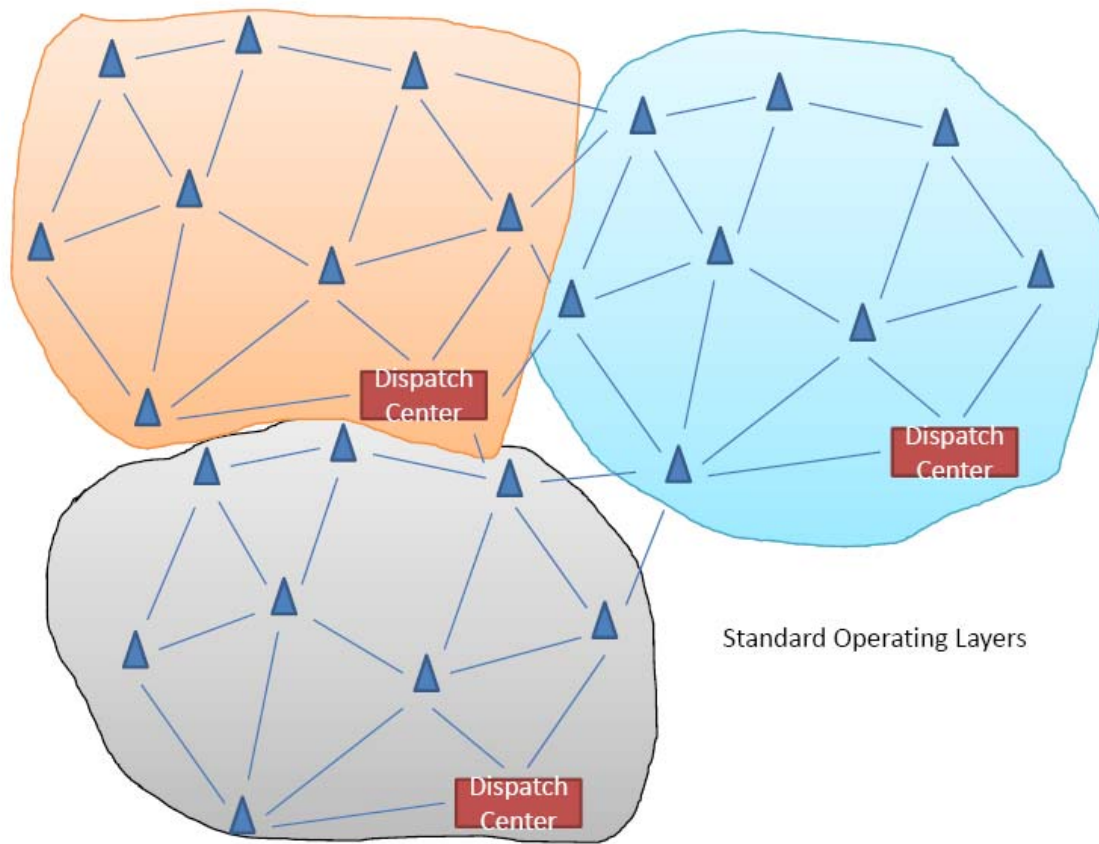


Figure 33 - Normal layering

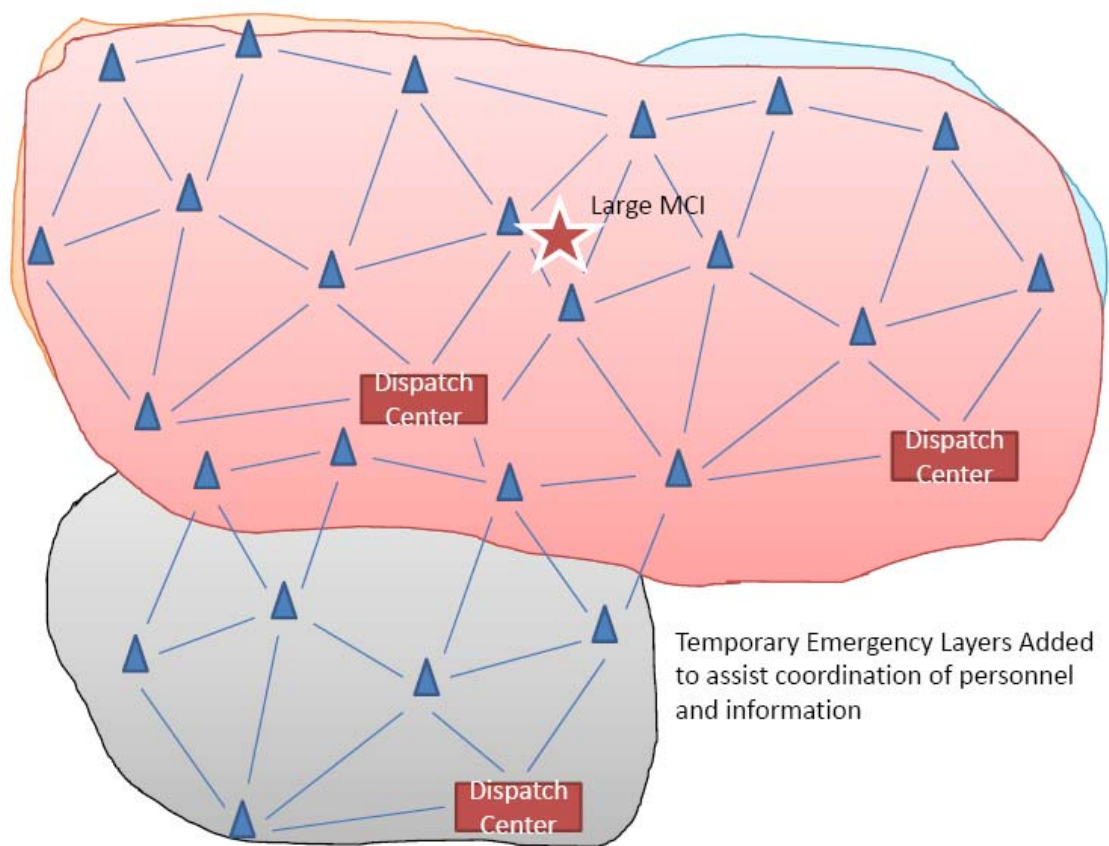


Figure 34 - Emergency Layer

End-User Requirements

While the goal of the TACSTACK is a particularly complicated one, it also needs to be simple and easy to use for the end users. The users of the system do not care how voice and data are being routed or what the bandwidth is throughout the system, they just need to transmit from point A to point B. With that in mind, the team has come up with some preliminary requirements to ensure that end-users have a simple yet powerful interfacing tool for the TACSTACK.

Mobiles/Portables

Once the RF planning has been complete and frequencies assigned throughout the region for TACSTACK operation, all mobiles and portables will need to be programmed with these channels. While it's not important how they are programmed, it would be simplest for them to

be entered in the mobiles as 'TACSTACK Fire 1' or 'TACSTACK Police 2', etc. This format will allow dispatches to easily assign their units to the appropriate channels in the event of a large-scale emergency.

Dispatch Centers

The control points for the TACSTACKs will primarily reside at dispatch centers throughout the system. Dispatches will have a computer which is linked to the TACSTACK network and is constantly checking the status on the network, the antenna sites, repeaters, etc. Dispatchers will also have the ability to request and implement temporary system changes, or layers, to the TACSTACK routing configuration. This is to say that a dispatcher can send a request out across the system requesting that different towers and frequency bands simulcast together around an incident. The dispatcher then also has the ability to release these temporary layers once the incident has passed or the layer is no longer needed.

Since there is a simple computer running as a client on the TACKSTACK network to create temporary layers, there is even the possibility for an incident commander to use a laptop at the incident to securely log on to the TACSTACK network and check repeater status' and create temporary layers.

Possible Hardware Configurations

Motorola

Motorola offers the most widely trusted and supported hardware in the public safety industry. Unfortunately, its products are extremely expensive compared to its competitors. The current base station model, the GCP 8000, features ASTRO 25 support for RF and simulcast communications. This protocol is P25 compatible, but is not a true P25 system. The GCP 8000 is a software defined radio, which allows for extensive feature upgrades. Extra components are necessary in order to provide critical features such as voting. There is no support for Low band VHF frequencies.

While Motorola makes up the majority of the current Public Safety Integration Center (PSIC), there is a desire to move away from Motorola if possible. Motorola equipment usually requires

expensive service agreements and Motorola technicians to do initial setup and configuration. The goal of the TACSTACK is to be easy to configure on the fly as well as a cost effective solution. Modifications to the system that would require a technician to come to site is not a feasible solution in an emergency.

Since Motorola is the market leader in the field, all TACSTACK equipment will most likely have to be able to interface with a preexisting Motorola system. There will be a lot of work required to link Motorola systems to other manufacturer's systems. Again, once development is under way, the extent in which Motorola hardware is used will be explored.

Tait Electronics

Tait Electronics offers the TaitNet P25 system, which uses TB9100 base stations. It offers extensive features for simulcasting including distributed voting and cross site transmission via VoIP. Tait does not support low band VHF frequencies. Tait's name does not yet have industry wide trust. While the hardware provided by Tait meets and exceeds the requirements of the TACSTACK, it has not yet established its name and it may be hard to push this as a primary manufacturer of TACSTACK equipment.

Daniels Electronics

The solution from Daniels Electronics is the cheapest and most feasible for testing purposes in the immediate future. All of the hardware from this company is simple and highly modular, making it a good choice for the TACSTACK. The Daniels Electronics solution also offers a higher level of in house serviceability and is the only major manufacturer to fully support low band VHF frequencies. Unfortunately, the company lacks the industry-wide trust that Motorola and M/A-COM have gained, meaning it may be less easily accepted by this projects' contractors. For a full price list of required Daniels Electronics equipment, see Table 2.

Table 2: Daniels Electronics TACSTACK Price List

Description	Stock Code	Frequency	Price
Transmitter	VT-4E150-00-800	136-174 MHz	\$1,635
Transmitter	UT-4E450-00-800	406-470 MHz	\$1,635
Transmitter	UT-4E500-00-800	470-520 MHz	\$1,635
Transmitter	UT-4E850-00-300	799-869 MHz	\$1,635

Transmitter	VT-3H035-SXA300	29-38 MHz	\$1,635
Receiver	VR-4E150-A0-000	136-174 MHz	\$1,980
Receiver	UR-4E420-A0-000	406-430 MHz	\$2,255
Receiver	UR-4E500-00-000	470-520 MHz	\$2,255
Receiver	UR-4E800-00-000	806-824 MHz	\$2,255
Receiver	VR-3H035-SWA200	29-38 MHz	\$1,980
Amplifier	AMP-140-110-D1P	136-144 MHz	\$2,415
Amplifier	AMP-P10-2GA1-C3	406-426 MHz	\$2,525
Amplifier	AMP-P9-2K1-C1	806-870 MHz	\$2,615
Amplifier	AMP-P10-2AA1-C1	30-36 MHz	\$3,245
Duplexer	DUP-136-174EKP	136-174 MHz	\$715
Duplexer	DUP-406-512MLN	406-512 MHz	\$1,475
Duplexer	DUP-806-896EYCB	806-896 MHz	\$510
Multiple Receiver Subrack	SR-39-3		\$795
Multiple Transmitter Subrack	SR-39-4		\$1,125
Standard Subrack	SR-39-1		\$860
40 Amp AC Power Supply	PSA-12-40-RB-00		\$1,405
Stationary Rack Cabinet	ES-1-B		\$210
Digital Base Control Card	CI-BC-4E-00		\$1,100
Digital Repeater Card	CI-RC-4L-00		\$690
Multiple Link Controller	CI-RC-4M		\$2,750
Universal Interface Card	UIC-4-00		\$1,925
	SM-3-H0-014-00		\$670
Base Station Speaker Panel	A-PNL-SP-01		\$270
			\$44,200

Other Hardware Providers

Companies such as Team Simoco and MA COM also provide hardware that could be used in the TACSTACK hardware system. They were examined and validated as potential choices but when a prototype is to be created, they, like Tait, Motorola and Daniels, would need to be reexamined to confirm they fit all of the requirements.

Backbone Capabilities

To maintain the critical backbone network discussed previously, there need to be durable and redundant data links between all of the TACSTACKS in an attempt to maintain this critical link in even the most disastrous of situations. The ideal network for data link between the TACSTACKS would be a mesh network. Given the costs and large amount of licenses required to accomplish this, the recommendation is that as many of the following links be used between TACSTACKS to reduce the chance of a single point of failure.

Fiber Optic

Many communities have private fiber networks and these could be used to connect TACSTACKS within that community to TACSTACKs of surrounding areas. Benefits of using fiber optic connections between the sites include large, dedicated bandwidth as well as the security that comes with using a communities private fiber optic network.

Microwave

Using a microwave link between sites is currently a fairly common practice and could be implemented excellently for an effective TACSTACK solution. Microwaves bandwidth would be licensed to interconnect sites which many not have any other means of connection. Microwave links would only be beneficial if they are used between a variety of sites and not used to link many sites directly to a single, larger site. Doing this cause the microwave links to have a single point of failure and have the chance of bringing down multiple sites if the main microwave site goes down.

WiMAX

WiMAX is still a developing technology but it would be utilized to maintain connectivity to the TACSTACK backbone network. WiMAX boasts more bandwidth than traditional (1G/2G/3G) cellular networks and also has larger potential coverage radius. Since not many companies and industries have picked up WiMAX yet, there is available spectrum which could be licensed exclusively for a secure public safety network which the TACSTACKs could utilize.

Cellular

Although there are some conflicts between the public safety community and cellular carriers, there is a chance that their expansive network could be utilized to maintain the backbone network in large-scale disaster situations. As the world community becomes more and more reliant on cell phones, the cellular carriers have been improving reliability of their networks both during normal operating times and during natural disasters. There is the possibility that agreements could be established that would ensure dedicated bandwidth for fixed sites (TACSTACK locations) in emergency situations. Since many cellular sites now have battery

backups and generators, there is a good chance that if other utilities are lost in the area, cellular sites would still be able to function.

Required Bandwidth

There have been no calculations done regarding the required bandwidth for the TACSTACK network. Since there is no prototype yet, it is impossible to begin to calculate how much bandwidth would be required. Also, sample transmission logs would need to be examined to see how much traffic occurs on a typical day and during mass casualty incidents.

RF Coverage Modelling

The team used a free piece of software called Radio Mobile to simulate coverage while analyzing the scope of a Commonwealth-wide TACSTACK implementation. Using the simulations the team was able to see where coverage would need to be reinforced and where there might be unnecessary repeater coverage overlaps. While there was no formal analysis done into analysis, the concept was proved feasible through a small example done. Appendix D has a copy of the slide show the team presented on the proof of concept.

Conclusion

The goal of the PSIC was to create an environment where a multitude of interoperability tasks could be performed. Ultimately, it is supposed to be a laboratory for student use, a testing facility for public safety officials, and a demonstration area for a wide range of radio equipment that is totally unbiased by manufacturers. Presently it is absolutely a useful tool for student use and thanks to several connections made with members of the public safety radio industry is well under way to becoming a showcase facility for multiple radio manufacturers' equipment. Because so little documentation for the existing equipment is available, the PSIC does not yet function as an area where public safety department officials could come to test new equipment for interoperability. With some further documentation and reverse engineering, the PSIC could certainly become an invaluable tool for public safety officials.

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Appendix A: PK-12 Packet Modem and RNET 450s Information

The information in this section has been copied from a former MQP that utilized these two pieces of radio equipment. The MQP used is: “A GPS-Based Remote Hazard Detection System – II, A Major Qualifying Project Report submitted to the Faculty of the Worcester Polytechnic Institute” by William E. Brother, Jonathan P. Day and John M. Zaghi and Advised by Dr. William R. Michalson, Ph.D. and Wilhelm H. Eggimann, Ph.D..

8. Communications Specification and Design

Communication between the on-board radio and packet modem and the combination located at the switch site is used to determine the status of a particular switch site. Successful communication equates to the switch being correctly positioned allowing the train to successfully continue along the mainline track. This section provides an overview of the components used in the communications system and discusses some shortcomings in the present communications system along with possible solutions.

8.1 Wave Propagation

This section discusses the attributes of the frequency presently used in the project, 452 Mhz. This frequency is in the lower UHF band and causes certain communication challenges.

8.1.1 The UHF Band

Historical belief was that frequencies above 30 Mhz could only follow line-of-sight paths. Over the years this proved to be false. Sea path communication at frequencies over 500 Mhz were successful at up to 168 miles. Communication in the upper bands has improved with the development of several techniques. The problem with the application of many of these methods to our system is that these methods are weather dependent. Our system must be reliable in *all* conditions, including periods of high sunspot activity, rain, snow, etc. Therefore, the basis of this study is to investigate line-of-sight performance from the system and determine if it meets our specifications. We will consider the use of digipeaters where line of sight communication is impractical or impossible.

8.2 The Motorola RNET 450S Radio

The RNET 450S is a small two-watt telemetry radio. It measures 3.30 inches long, 2.7 inches wide, 1.52 inches high and weighs only 11 ounces. This UHF transceiver supports both voice and data. The radio has a female BNC antenna connection and a DB15 connector on its front face (see figure 14) and also has eight DIP switches mounted on its audio board for accessing various features (see Tables 7 and 8). These radios operate at 452 MHz and replace the Motorola M10 transceivers originally used for the project that had 25 watts of transmitting power.

8.2.1 Connecting the RNET 450S to the PK12

Before connecting the radios to the modems for use, position their DIP switches to the appropriate settings for use in our system. Table 8.1 and Table 8.2 contain the Dip Switch functions along with their corresponding settings allowing the radios to function with our system.

Table 8.1- Audio Board DIP Switch Settings.

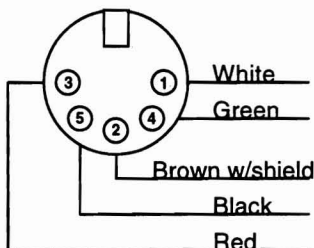
Switch	Function	Setting
1	Channel select bit 0 (CS0)	ON
2	PTT watchdog disable, ON = PTT watchdog disabled	ON
3	Data out mode switch one (see table 3.2)	OFF
4	data out mode switch two (see table 3.2)	ON
5	Channel select bit 1 (CS1)	ON
6	On = Data in has flat response. Off = Data has 6dB pre-emphasis	ON
7	Channel select bit 2 (CS2)	ON
8	PTT polarity select. On = PTT is active low (0V). Off = PTT is active high (5V)	ON

Table 8.2 - Data Out Mode Dip Switch Function Settings.

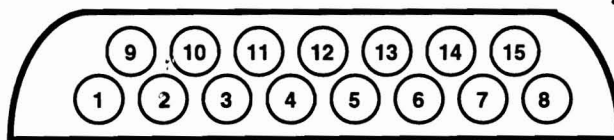
Switch 3	Switch 4	Function
ON	OFF	De-emphasized data out
OFF	ON	Flat data out
OFF	OFF	No data out
ON	ON	Invalid selection

After making the above settings, the radios are ready for use. The next step is to assemble the cable to connect the PK12 to the radios.

The modem's 5 pin DIN plug, located on the rear panel, provides the connection to the RNET 450S. Shown below is the pinout of this plug along with the corresponding wire color code for the cable provided with the modem.

**Figure 8.1 - PK12 5 pin DIN connection.**

A DB15 connector provides an interface to the radio. Below is the pinout of this connector:

**Figure 8.2 - DB15 I/O Connector on RNET 450S.**

The following table illustrates the connections necessary to interface the RNET 450S to the PK12 packet modem:

Table 8.3 - Packet Modem to Radio Connections.

PK12 Packet Modem			RNET 450S Telemetry Radio	
Wire Color	function	to	Pin Number	Function
Green	To Speaker Audio	to	8	Data Output
White	MIC	to	7	Data In
Brown w/Shield	MIC Ground	to	15	Ground
Red	Push to Talk	to	14	Push to Talk
Black	Squelch	to	10	Clear to Send
N/C	N/C	to	6	+12 VDC
N/C	N/C	to	15	Ground

8.2.2 Modem Level Settings

The PK12 modem contains a potentiometer on the rear panel to adjust the transmit level output of the modem. The modem operating manual specifies that this level be set to produce a 3 kHz deviation in the transmit signal for optimum performance. The RNET 450s radios specify that a 40 mV RMS input signal produces a 3 kHz deviation. While monitoring the output level of the modem (the white wire off the modem plug, see Table 8.3) on an oscilloscope, toggle the modem into calibration mode from the “cmd:” prompt on a terminal by pressing “k”. The oscilloscope will then contain the sine wave produced by the modem that feeds into the “data in” terminal on the RNET 450s (pin 7 on the RNET plug, see Table 8.3). In this mode, pressing the space bar on the terminal toggles the “mark” and “space” signals from the modem, which correspond to binary ones and zeroes. Once the data waveform is on the scope, turn the potentiometer on the rear of the PK12 to set the level to 40 mV RMS. Once completed, the transmit level should be correct. The use of a deviation meter or a spectrum analyzer could verify that a 3 kHz deviation is present.

On the other end of the system, determine if the receive level is within specification. Once the radio on the receiving end picks up a signal, it feeds it to the modem through the green wire on the modem plug that connects to data out on the RNET 450s (pin 8 on the RNET, see Table 8.3). The signal from the radio has a 2.5 volt DC offset which the modem strips away through AC coupling. This signal then enters the TCM3105 FSK modem chip inside the modem. The level monitored at pin 4 on this chip determines if the receive level is within specification. This level measures 400 mV peak to peak. The specifications for the TCM3105FSK say that this level must be between 300 mV and 780 mV peak to peak. Therefore, the receive level is within specification. These settings, when verified, result in an optimum hardware interface between the radio and modem.

8.2.3 Modem Software Settings

Software directly controls all of the modem parameters except for the transmit level. The greatest concern for this application is the settings that control the radio. The modem keys the push to talk, determines how long to wait after the push to talk is activated before data can be sent (all radios require some delay), how long to wait after receiving a connect signal to acknowledge, as well as many other factors which affect system performance. When set properly, the reliability and speed of the system improves. This is a concern because this part of the system can reduce system latencies. The specifications of the radio in use determines many

of these settings. Trial and error is also of help in optimizing the system. Both “real world” testing (testing the performance outdoors) and using the variable attenuator method described in Section 8.3.2 are methods of evaluating the system. Below is a list of the modem settings and a description of each. Note that the letters in capitals are abbreviations for the following commands, and <CR> after each command indicates the “ENTER” key.

To program the PK12's, use a software communications package (the team selected Qmodem™) and a serial cable to interface a Personal Computer to the packet modem. The following sections contain an overview of the different modem commands and their configurations used in this project.

8.2.3.1 Modem Call Sign

The modem call sign is the first parameter to set. This refers to the “name” of the modem and is what makes each packet modem uniquely addressable. The call signs for the modems at the switch sites correspond to the track mile marker denoting the switch site. The modems located on the locomotives usually have the call sign “train.” The command for setting the call sign is MYCALL *name* <CR> where name refers to whatever you wish to call the modem.

8.2.3.2 EXPert Mode

The next command is EXPert. This command protects novice users from altering parameters that they normally should leave at the default settings. To allow access to these settings, disable this safety feature. To do this, type EXPERT ON <CR>.

8.2.3.3 AUdelay

AUdelay is the next parameter to define. This parameter introduces a delay between the activation of PTT (push to talk) and the modem generating tones. For our transceivers, a delay of 20ms is optimal. To accomplish this, enter AUdelay 2 <CR>. This is the default setting for the PK12. Note, AUdelay is lower than TXdelay by a setting of 10 for proper performance from most radios. An explanation of TXdelay follows in the next section.

8.2.3.4 TXdelay

TXdelay controls how long to delay before sending packet data after keying the PTT line of the transmitter. This parameter works with AUdelay. After keying the PTT line, AUdelay sets up a time delay before the modem generates tones, then TXdelay sets up a delay before sending actual packet data. This illustrates why TXdelay is greater than AUdelay by a setting of 10. For the system, this difference is adequate. Therefore, setTXdelay to 12, which corresponds to 120 ms, by entering: TXdelay 12 <CR>.

8.2.3.5 NEwmode

NEwmode determines how the PK12 responds when a link terminates. When NEwmode is on, the PK12 returns to command mode when the link terminates or if a connect attempt fails. When NEwmode is off, the PK12 remains in its previous state until manually “forced” to return to

command mode. The system requires this “ON.” To do this enter: NEWmode ON <CR>. This is the default for the PK12.

8.2.3.6 PPersist

The next parameter, PPersist, determines whether the PK12 uses PERSIST or DWAIT for its carrier sense multiple access (CSMA) procedure. Our system uses the newer PERSIST procedure. To activate PERSIST, enter PPersist ON <CR>.

8.2.3.7 DIGIpeat

The last modem setting is DIGIpeat. Unless using a packet modem as a digipeater, set DIGIpeat to off. When this function is on, the PK12 acts as a digipeater. This means that it will re-transmit all packets it hears. Batteries supply the power for the switch site hardware and transmitting draws the most current. Therefore, disabling this function will eliminate all radio transmissions unless it is responding to a request from a train unit. To disable this function enter: DIGIpeat OFF (ret). The following table sums up the modem settings:

Table 8.4 - Modem Software Settings

Parameter	Setting	Description
Mycall	name	Enters modem call sign
EXPert	ON	Allows access to expert commands
Audelay	2	(20ms) delay between PTT and applied tones
Newmode	ON	PK12 switches to command mode
Txdelay	12	(120ms) delay before packet data is sent Must be a setting of 10 greater than AUdelay
Ppersist	ON	Type of CSMA procedure used
DIGIpeat	OFF	Disables use of PK12 as a digipeater

8.3 Communication System Test Procedures

Generally, the means of evaluating communication system performance is statistical analysis. No communication system is 100% reliable. When specifying a system, determine the requirements that the system must possess for its intended application. Examples of these requirements are: the probability of false alarms, the probability of detection, and the time between false alarms. Determining if a given system meets these requirements is the first challenge, and if not, how to make it meet these requirements is the second challenge. Discussed below are some methods for evaluating the performance of the current communications equipment.

8.3.1 Mathematical Modeling

Mathematical modeling plays a healthy role in any communications system analysis. In the following section there is an equation relating distance and frequency to the amount of attenuation of a signal. Using this relationship, calculate the attenuation of a 452 MHz signal at distances of two and four miles. The results (95.7 dB and 101.7 dB respectively) accurately model the attenuation of a signal using the variable attenuator also discussed below.

Another equation which plays a role in the analysis is

$$S_{\min} = K_o T_o B_n F_n \left(\frac{S_o}{N_o} \right)_{\min},$$

S_{\min} represents the power of the minimum detectable signal (in Watts). K_o is Boltzmann's constant which is 1.38×10^{-23} . T_o is the temperature in °Kelvin, B_n is the signal's intermediate bandwidth, F_n represents the noise figure, and

$$\frac{S_o}{N_o},$$

is the signal to noise ratio at the receiver. The above equation allows us to calculate the minimum signal to noise ratio given the other parameters. The next step is to specify a T_{fa} , the minimum allowable time between false alarms. False alarms, in this case, represent that the signal went undetected by the receiver. Once specified, determine (from a set of curves) the minimum signal to noise ratio required to produce our specified T_{fa} . Compare this with the calculated signal to noise ratio to see if it meets the specification. Using another set of curves with the calculated signal to noise ratio and the known intermediate bandwidth (B_n), determine from another set of curves the probability of detection. If this meets the specification, the system should perform as specified for the time between false alarms and the probability of detection. If it falls short of its mark, determine the necessary signal to noise ratio to give the probability of detection required. Finally, research what will help to achieve this ratio.

The equation

$$P_r = \frac{P_t G_t G_r L^2}{4\pi R^2},$$

computes the power received from a transmitter given the transmitted power (P_t), the gains of the transmitting and receiving antennas (G_t and G_r respectively), the wavelength (L) and the distance between the two antennas R . If P_r is replaced with S_{\min} in the equation:

$$R_{\max} = \sqrt{\frac{P_t G_t G_r L^2}{P_r (4\pi)^2}},$$

the result is the maximum (free space) distance that the signal could travel and still be detected.

The equations discussed thus far represent the effects on signals in free space. However, when taking into account "real world" signals, there are other factors that also play a role. The propagation factor, (F_p), is one of these factors. This term represents the effects of multi-path propagation on the received signal. The equation is

$$F_p = \frac{4 \sin^2(2\pi H_t H_r / LR)}{LR},$$

where H_t and H_r represent the height of the transmitting and receiving antennas respectively, L represents the wavelength of the signal, and R represents the distance between the two antennas. To obtain a more accurate picture of the power received, take P_r and multiply it by F_p . Looking at the equation for F_p , we see that this factor can multiply the power received by a factor of four

when the sine is at its greatest value (1). This is constructive interference. The result could also be a multiplication of the received signal by zero when the sin is at its smallest value (0). This is destructive interference. It is obvious that the heights of the antennas will remain constant, but the distance between the radios, R , is constantly changing as the locomotive approaches.

8.3.2 The Variable Attenuator

To simulate a separation between the transceivers so that an effective laboratory simulation is possible, the team located a variable attenuator. This attenuator is adjustable from 3.3 to 120 dB. Measuring the signal attenuation of one of the radios with this device in series with the antenna verified its calibration. In free space, the distance traveled and the frequency of a signal are two determining factors of its attenuation. To calculate the attenuation of a signal based on these factors, use the formula:

$$\text{attenuation (dB)} = 36.6 + 20\log(fm) + 20\log(d),$$

where fm is the operating frequency in MHz and d is the distance between isotropic antennas in miles. This formula models the free space attenuation of a signal. If we use it to calculate the attenuation of a 452 MHz signal over two and four miles, we will see that the resulting attenuation is 95.7 dB and 101.7 dB respectively. The variable attenuator easily handles these values and will serve as an effective model for the communications distance we must achieve. Of course, this is only taking into account line of site communications. Along the actual railroad, there are many obstructions such as hills and bridges which all but eliminate line of site communication. To better simulate the effects of these obstructions and the affect of hardware changes upon the system, it may be necessary to assemble an additional attenuator.

8.3.3 Computer Simulation

The reliability of a communication system is a statistical analysis which represents the possibility of errors in data transmission. Written to simulate the communications portion of the system, a computer program acts a test vehicle for analyzing system changes. The current program sequentially connects and disconnects from a remote "switch site." The program logs the results of the connect and disconnect attempts to a file and at the end of the simulation parses the file and reports the number of failures. The program prompts for the number of connect attempts to simulate when it is first run. Using this simulation program coupled with the variable attenuator discussed above, it was possible to optimize many of the communications system parameters, such as the software settings and hardware interface, discussed earlier. The current system settings should produce optimal results with the current hardware in use. To determine the effect of further system alterations, the assembly of an additional attenuator may be necessary. This will better simulate the effects of hills and bridges and other obstructions which hinder communications.

8.3.4 Real world Testing

Modeling the system is the first step. The second step is determining if the model matches the real world application. Real world testing procedures involve locating the switch sites which have the greatest potential to cause the highest degree of signal attenuation due to obstructions such as trees or bridges. We then test the current system here to determine how it functions.

This involves attempting to connect to a radio and packet modem located at the switch site from two miles away. If the radios connect successfully, we then transmit data and log it to a file at the receiving end for comparison to the original data.

8.4 Possible System Upgrades

As mentioned previously, no communications system is 100% reliable. This section attempts to face the second challenge: how to improve the current system to meet specified system requirements for which it falls short.

8.4.1 Line of Site Communication

Just as the name implies, line of sight communication is where the transmitting and receiving antennas have an unobstructed view of each other. Without trees, bridges, or other obstructions, radios have line of sight communication as long as the distance to their respective radio horizons overlap. In other words, each radio has a specific distance it can reach based on the height of its antenna. The formula used to determine this “radio horizon” is

$$S = \sqrt{2H} ,$$

where h is the height of the antenna above average terrain in feet, and S is the distance to the radio horizon in miles. If we specify that we want each radio to have a radio horizon of 2 miles (for a combined total LOS distance of 4 miles) this equation dictates that the antenna must be only two feet above the height of the average terrain. As a possible aid to the communications difficulty, it may be feasible to locate the transmitting and receiving antennas in such a manner that they clear the surrounding obstructions, or implement digipeaters to provide LOS. The computer modeling discussed earlier is an effective method of evaluating LOS system performance. This test has tentatively demonstrated that LOS communication produces acceptable results (probability of detection > .99), although further tests are necessary to prove this beyond a doubt.

8.4.2 Directional Antennas

Directional antennas have the capabilities for configuration to exhibit increased signal gain in certain directions. The style of antenna appears perfect for this system because the train always approaches the switch site from one of two directions. This suggests a bi-directional antenna for the switch site and a unidirectional antenna for the locomotive. The increased gain will increase the signal to noise ratio and help increase the probability of detection; thus increasing system reliability.

8.4.3 Digi-peaters

In packet radio, it is common for one station to desire to reach another station beyond its immediate radio range. Hilly terrain, trees, bridges and other obstacles can place two stations out of range. If packet station exists in between the two stations who desire to communicate and both stations are capable of reaching this intermediate station, the intermediate station can act as a digi-peater. To illustrate, the first station sends data to the distant station by “relaying” it through the intermediate station. The intermediate station receives the transmission and re-

transmits it to the distant station. Any packet radio system can act as a digi-peater. Using digi-peaters at strategic locations along the track is another way to overcome signal attenuation due to foliage and structures. However, using this approach will increase system latencies due to increased connect and disconnect times associated with re-transmitting the packet. In other words, each packet station receives and re-transmits the packet multiple times in order for it to reach its destination. Digi-peaters can be an effective means of increasing communication distance and reliability. Their use in the current system has the potential to help improve the communications.

Appendix B: PK-12 Packet Modem and RNET 450s Information

Continued

The information in this section has been copied from a former MQP that utilized these two pieces of radio equipment. The MQP used is: “A GPS-Based Remote Hazard Detection System – II, A Major Qualifying Project Report submitted to the Faculty of the Worcester Polytechnic Institute” by William E. Brother, Jonathan P. Day and John M. Zaghi and Advised by Dr. William R. Michalson, Ph.D. and Wilhelm H. Eggimann, Ph.D.. This section was originally an appendix in the above mentioned MQP. It is presumed that this appendix was taken from the original MQP report by William Cidela, Chris Mangiarelli and Michael Roberts although no direct citation is given.

Appendix I - Original System Communication Specification

The following is the specifications for the communications system used by last years project. It is supplied as an additional reference to the PK12 packet modem and the Motorola M10 radios.

Communication System Overview

The communication system used in this system is comprised of Advanced Electronics Engineering, AEA, PK-12 packet modems, connected to Motorola M-10 transceivers. The packet modems are used so that each and every switch will have a unique call sign. This enables the system to call to, and get a response from, only the switch sites that it wants. The M-10 transceivers are supplied by the P&W RR, and are similar to the ones in use by the P&W at this time. They operate in simplex mode at a frequency of 452 MHz.

The Pk-12 Packet Modem

The PK-12 is a 1200 baud, packet-only controller, designed to be used in conjunction with a standard RF transceiver. A packet only controller is similar to a modem in a computer except that, instead of converting the digital signals for use on the phone lines, it converts them for use in radio frequencies. The PK-12 offers ease of use combined with many excellent features that aided in the successful completion of this project. The cost of the PK-12's were \$109.00

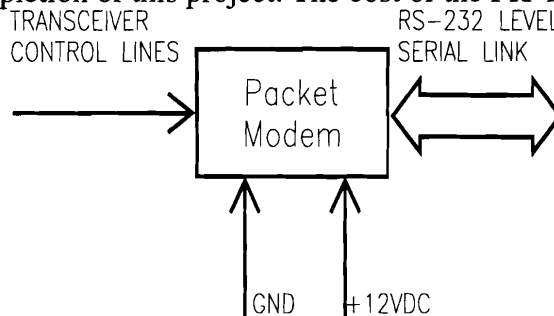


Figure 0.1: Packet Modem Functional Block from Overall Diagram

each. The PK-12 operates at +13 VDC but, in low power mode, can operate with a +9 VDC source. The connection to the radio is a 5-pin DIN type connector. The connection to the terminal is an RS-232 25-pin DB-25 female connector. Terminal data rates from between 110 to 19200 BPS are available. A data rate of 9600 BPS is used for this system at this time. A copy of the PK-12 operating manual will be kept on file with this report.

Connecting the PK-12 to a Computer

The first thing to do when learning about the PK-12's is to test it using a computer setup as a 'dumb' terminal. When beginning to test the modems, make sure power

is properly applied. Simply connect a 12 volt regulated supply to the power cords, making sure that +12 goes to the wire marked with the white stripe. To connect the modems for testing, simply connect the modems to the serial port of a computer with an RS-232 cable and use a communications program, to 'talk' to the modems (Note: A null modem cable will not work with the PK-12,s, a standard serial cable is needed). When initially connecting the PK-12 to a computer the serial COM port must be set to between 300 and 9600 baud (9600 is preferred because that is the baud rate of the controller for the project) in TTY mode, with 8 data bits, 1 stop and no parity. With the port setup in this way, and the PK-12 connected with power, turn the modem on. Initially, the modem may not be set to 'talk' correctly to the COM port. To get it to do this, enter an asterisk, ' * '. This allows the PK-12 to check out the baud rate of the port and adjust itself accordingly. After doing this you should receive the following message:

```
AEA..PK - 12 Packet Controller
AX.25 Level 2 Version 2.0
Copyright (C) 1995 by
Advanced Electronic Applications, Inc.
Release 26.JUN.95
Ver. 7.1
```

cmd:

"cmd:" is the command prompt for this version of the packet software. Once you see this, you know that the modem is working. Now it is time to perform a 'loop-back' test. To do this place a jumper between the white and green wire of the DIN connector and plug it into the proper connection in the back of the PK-12. This allows the PK-12 to talk to itself.

With the jumper in place the required test is now performed. First, change the name of the modem by typing MY '*name*' where the *name* picked is the users choice. Once this is done the following message should appear:

```
MYcall was PK12
MYcall now PKBASE
cmd:
```

This signifies that there was a change to MYCALL, or the 'name' of the modem. With the new name, a test should be performed to have the modem try to connect to itself. To do this, type *c name*. 'c' is to Connect followed by a space and then who you're trying to connect to. After typing this the following message should be seen:

```
*** Connected to PKBASE
```

(NOTE: there is also no more command prompt)

Because the modem is now connected to itself, anything typed followed by <ENTER> would be followed by the same message echoed to the screen again. This shows that a 'packet' is sent and the modem is working correctly.

To disconnect from any connection, simply type CTRL-C which will now bring back the command prompt, cmd:. Now enter a 'd' signifying Disconnect. The following message will be seen upon proper disconnect:

```
*** Disconnect: name
```

This concludes the initial test for a packet modem. The following section will describe the proper connection of the PK-12 to the Motorola M-10 transceivers. (Note: If other transceivers are used, refer to the copy of the AEA PK-12 users manual on file with Prof. William Michalson)

Connecting the PK-12 to a Radio

The following sections describe the connecting of the PK-12 to a Motorola M-10 transceiver.

Initial Setup the Motorola Transceivers

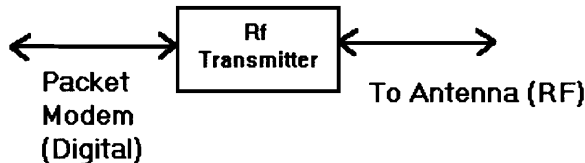


Figure 0.2: Transceiver Functional Block from Overall Diagram

First of all, the transceivers should be setup to use "Flat Audio" receive and transmit. To set up the transceivers for this, jumper JU551A must be changed from position B to A. To get at this jumper, simply remove the front panel (refer to radio illustrations fig. 4) and then the bottom cover. Under the bottom cover is the RF chassis shield. After removing this shield, the logic board is exposed. On the logic board, JU551A can be easily located. To change position of the jumper, simply pull up on the jumper, remove it, and replace it in the A position.

Disassemble Radio

Remove Control Head and Chassis Covers

1. Remove mounting screws for control head (Figure 1-1).

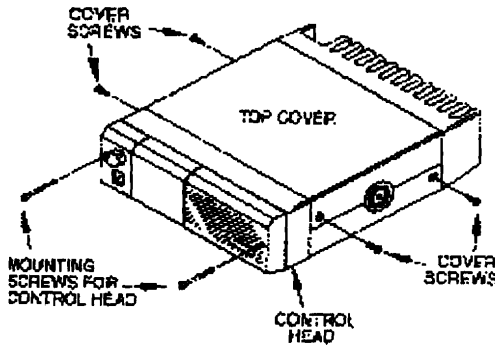


Figure 1-1. Mounting and Cover Screws.

2. Pull control head off and away from the radio
3. Carefully remove control head connectors from chassis.
4. Remove the two chassis cover screws from each side (Figure 1-1).
5. Remove top and bottom covers from chassis.

Figure 0.3 Disassembling the M-10 Radio

After the jumper position is switched, the wiring between the modems and radios should now be completed. The AEA PK-12 packet modems come with wiring harness for connecting to radio equipment. The plug for radio connections from the modems is a 5-pin DIN connector located on the back left hand side of the units. The following illustration, Figure 0.4, illustrates the DIN connector and the wiring diagrams for it.

Wiring Between Packet Modem and Radio

This section describes the wiring between the PK-12 and the Motorola M-10 transceivers.

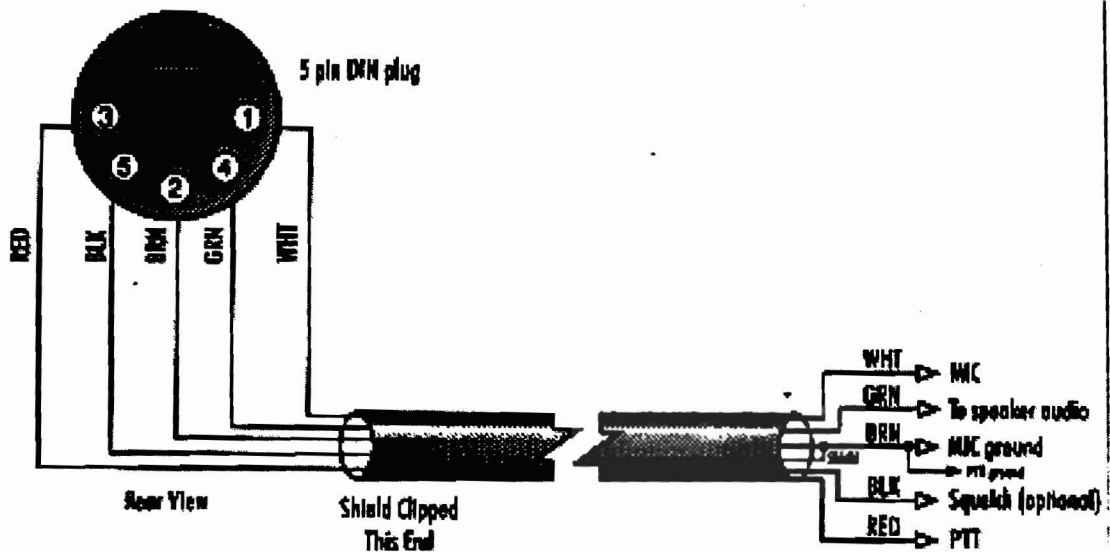


Figure 0.4: Wiring Between PK-12 and Radio

Shown below, Figure 0.5: Connector to packet modem for M-10 radio, is the wiring harness for the Motorola M-10 transceivers:

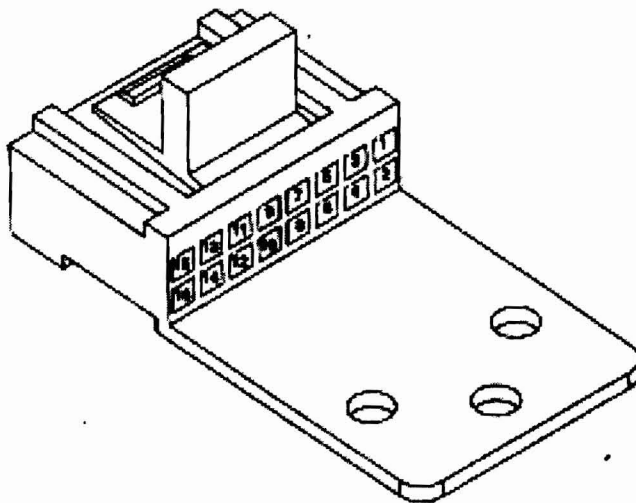


Figure 0.5: Connector to packet modem for M-10 radio

For the following list of connections, refer to Figure 0.4.

- Connection '1' of the modem, the white wire, goes to pin 5 of the radio plug. This is the Flat Transmit audio of the transceivers.
- Connection '2' of the modem, the brown wire, as well as the un-insulated wire, goes to pin 8 of the radio. This is signal ground.

- Connection '3' of the modem, the red wire, goes to pin 3 of the radio plug. This is the Push To Talk, PTT of the transceiver.
- Connection '4' of the modem, the green wire, goes to pin 15 of the radio plug. This is the Discriminator Output of the transceiver.
- Connection '5' of the modem, the black wire, goes to pin 8 of the radio plug. This is the un-squelched indicator of the transceiver.
- An optional connection would be to put a jumper across pin 15 and 16 so that any transmissions that are heard by the radios will go to the internal speaker of the radio.

Once the wiring is completed from the modems to the transceivers, the modems are set up for use as the system requires. The following section describes how to setup the modems as they are used in this system.

Setting Up the PK-12 For This System

To get the most range out of the modem/transceiver setup is to set the deviation of the signal to 3 KHz. To do this, the jumper, J3, on the PK-12 must be set on 'Lo'. This jumper is located near the top right hand corner in Figure 0.6: Component Layout for PK-12 Packet Modem. Some of the modems were set to 'hi' and some were set to 'lo'.

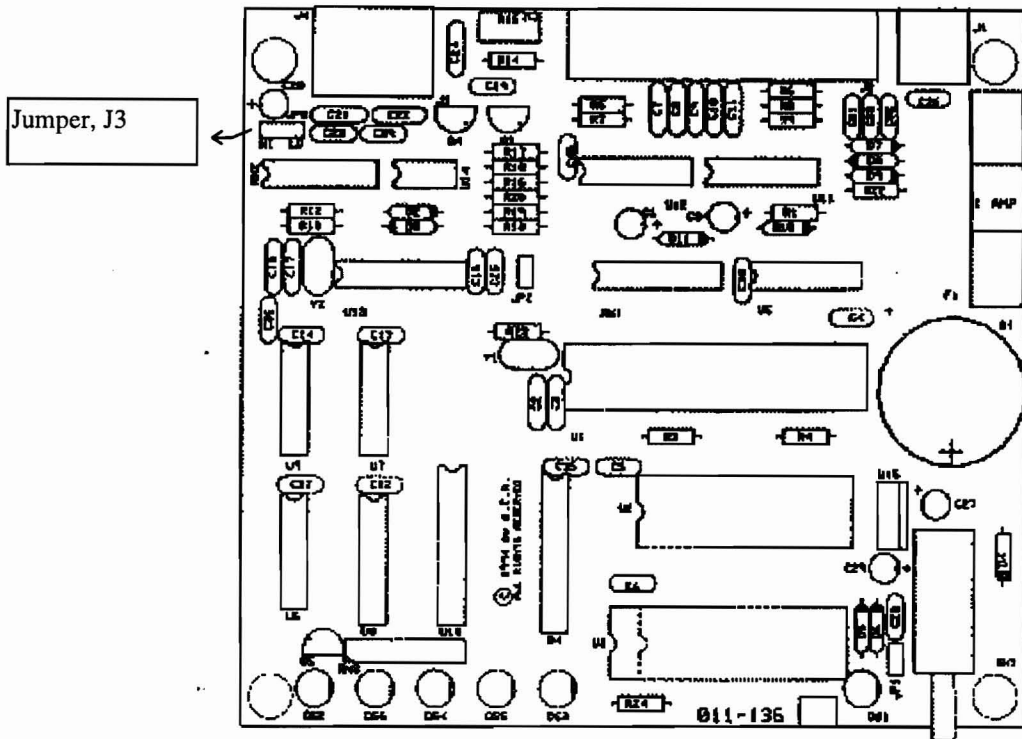
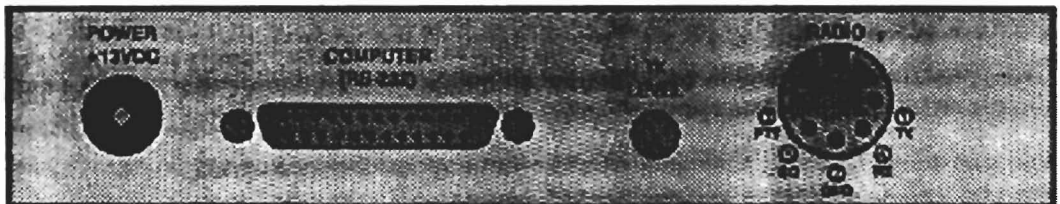


Figure 0.6: Component Layout for PK-12 Packet Modem

Now, with the jumper in the correct position, a deviation meter is used to calibrate the modems transmission deviation. To get the modem to constantly transmit, type *cal* and then ENTER. This puts the modems in calibration mode. Typing *K* will toggle the transmit on and off for calibration purposes. The adjustment for deviation is found on the back of the PK-12's, next to the DIN connector. It is labeled TX LEVEL as seen in fig. 7. Once the modems are set to 3KHz deviation, the adjustment control should be taped over so that they cannot be changed. The 3 modems already in use for this system have tape over the adjustments. With this accomplished, the modems can now be setup correctly for our system.



Rear View of the PK-12

Figure 0.7: Rear view of PK-12

The system is set up now for the fastest time for connecting and disconnecting from the remote modems. New modems will have to be set accordingly. To do this, connect power, as described earlier, and connect a serial cable to the

modems. Turn the modem on and press '*' and then <ENTER>. As shown previously, the following message should appear:

```
AEA PK - 12 Packet Controller
AX.25 Level 2 Version 2.0
Copyright (C) 1995 by
Advanced Electronic Applications, Inc.
Release 26.JUN.95
Ver: 7.1
```

cmd:

The following settings should now be set. Before this, however, a note should be made that, for all the following commands, any part of the command that is capitalized is all that needs to be used. An example of this is seen in the first command illustrated. When setting EXPert mode on or off, only EXP needs to be used.

First, to use all the commands needed you must first be in EXPert mode. To do this type:

```
EXP on <ENTER>
```

To get the fastest response times for the system both AXDelay and Txdelay have to be set accordingly.

```
AXD 10 <ENTER>
TX 15 <ENTER>
```

AXDelay must always be set at least a setting of 10 below Txdelay. AXDelay is used in combination with Txdelay as the amount of time (setting times 10mS) that the transmitter gets keyed before data is sent out.

So that the system will not interfere with the existing communication system used by the P&W, the system must be setup to wait 500mS after it has detected a carrier using its frequency. To do this, set DWait to 50.

```
DW 50 <ENTER>
```

The amount of DWait is multiplied by 10mS for the actual amount of time to wait after a carrier is detected. This is called debounce time.

To make use of the DWait time, the following setting must be set so that the Carrier Sense Multiple Access System, CSMA, is shut down.

```
PPersist OFF <ENTER>
```

The next setting, FRack, is the amount of time that the unit waits for an acknowledgment, before it retries.

FR 2 <ENTER>

Two seconds is the minimum FRack that should be used. This is set to its minimum setting because it aided in reducing any system latencies. The latencies referred to here are any delays in the system performance caused by the way the system is designed. The main latency, or delay, in the system is caused by the communications. Once the communication latencies are made to be as small as possible, system performance will peak. If the latencies are reduced in some other way, it is advisable to increase FRack by one or two to allow the modems more chances to get a valid connection.

The next setting will allow a program to control the modems without having to use the CTRL-C character to switch between transparent and command mode. In transparent mode, anything entered into the packet modem automatically goes out to the radio as a packet of data. In command mode, all the user commands can be accessed for adjusting the packet modems, connecting to other modems, disconnecting from any connected modems, etc.

NEwmode OFF <ENTER>

When a connection is made between two modems, they are in transparent mode meaning that anything typed by the host followed by <ENTER> will be considered data, and consequently will be sent as pure data. The system, as it is setup now, doesn't need to send data. It only needs to connect and/or disconnect. If a future system is setup to pass data back and forth from the modems, NEwmode should be set back to ON.

With the previous setting complete, the modems will work fine in the system as it is setup now. For any enhancements to the system, all the settings that the PK-12's use can be found in the aforementioned AEA manual. The next section will describe how the PK-12's can be setup for multiple I/O connections. This is one way that the system may possibly be enhanced, and it can be studied by a future project group.

Future Setup For Multiple I/O Connections

To get the modems setup to operate on more than one channel at a time, thereby enabling connection to more than one modem at a time, the following settings need to be changed.

The first thing to do is to setup a channel switch character. This will be the ASCII number of the character to be used by the host to change the channel of operation that it's currently using. The recommended switch is ASCII 7C (hex) or 'l', the pipe character. To do this, type:

CHSwitch 7Ch

The number 7C in hexadecimal refers to the pipe character. Once this is done, changing from one channel to another is as simple as typing ln <ENTER> where n refers to the numbered channel that is desired. (Note: The available channels are 0 through 9)

Once the switch character is set, the number of possible USers must now be set. To do this type:

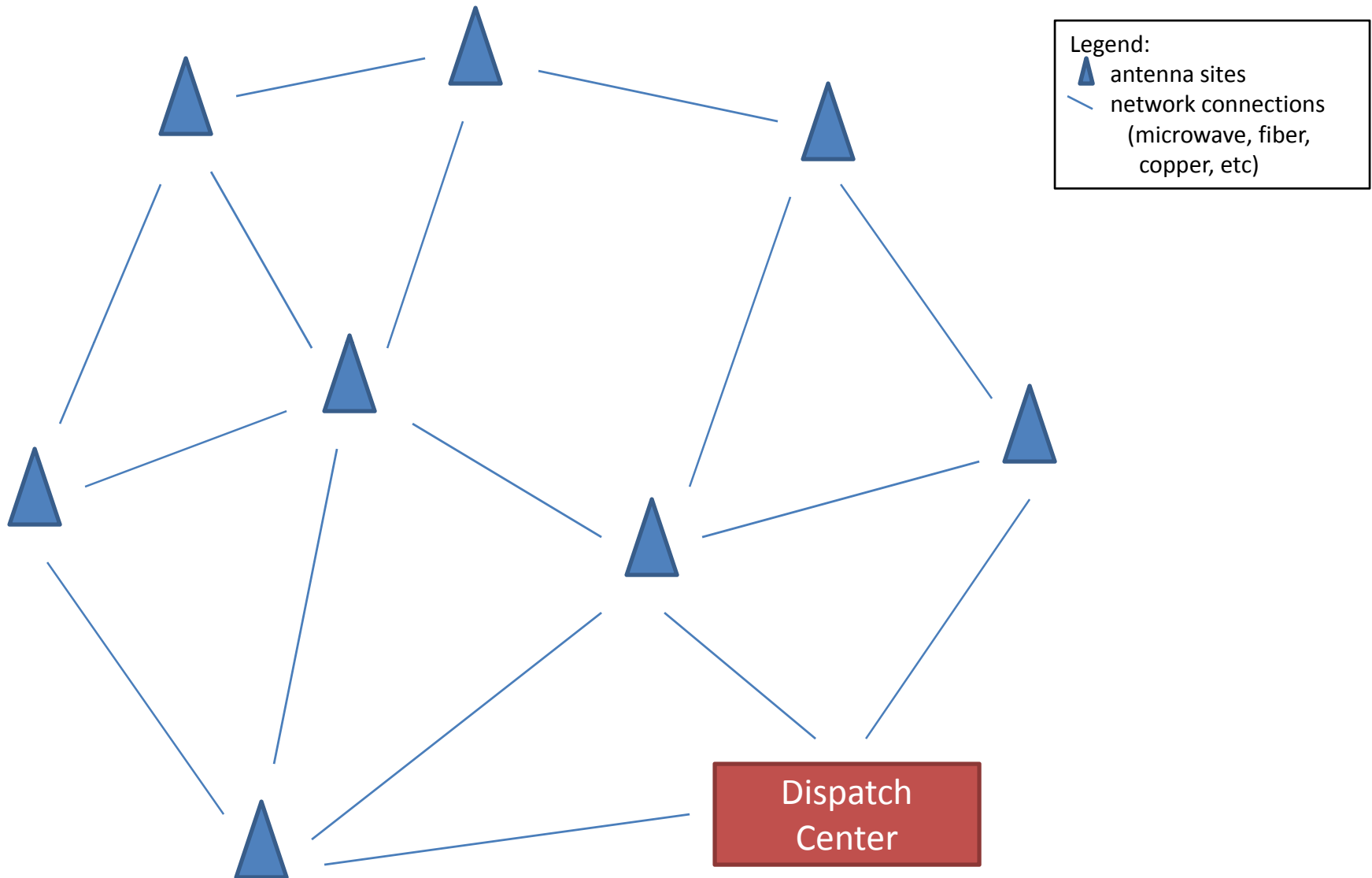
US n <ENTER>

where n must be set to a number greater than the default number one. Once the modems are setup for multiple connection, it is easy to tell who is connected and to which channel. Simply type CS <ENTER> and a list of all the channels and their status will be seen on the screen.

Appendix C: TACSTACK Concept Presentation

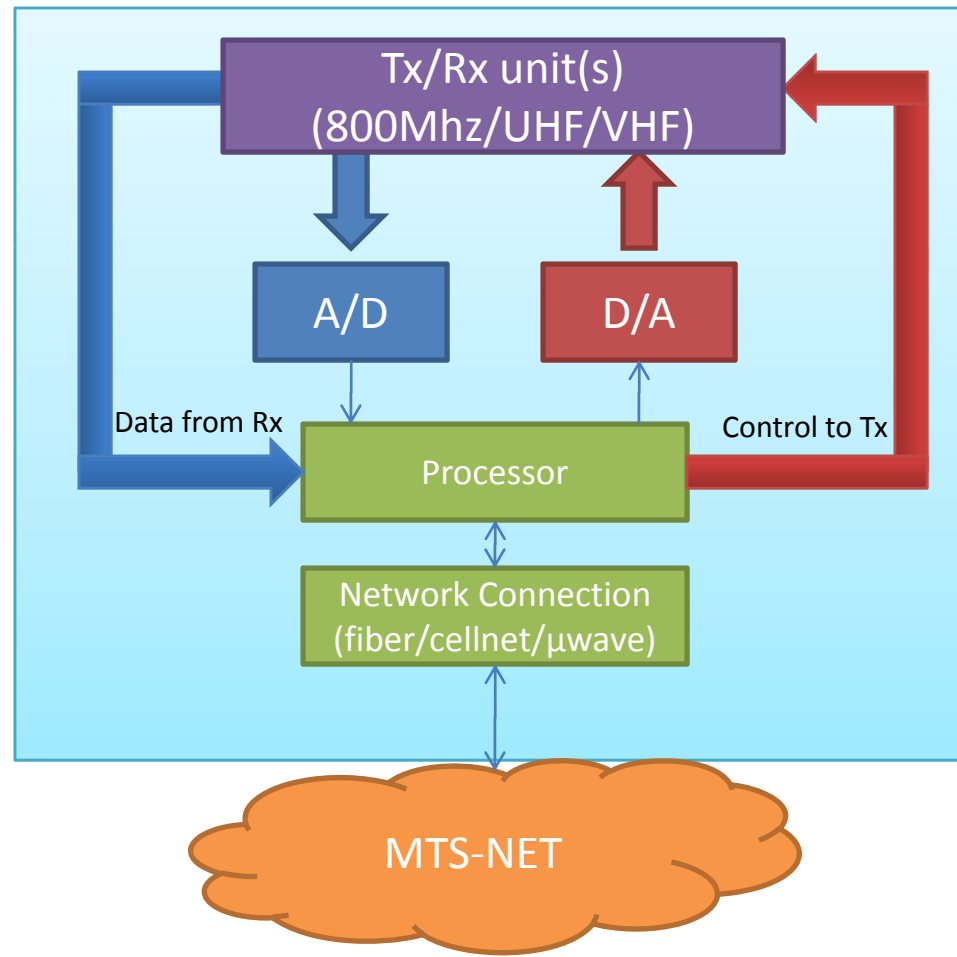
This section contains the entire slideshow presented by the PSIC team to Professor Michalson in June 2008.

Mesh RF Network Layout



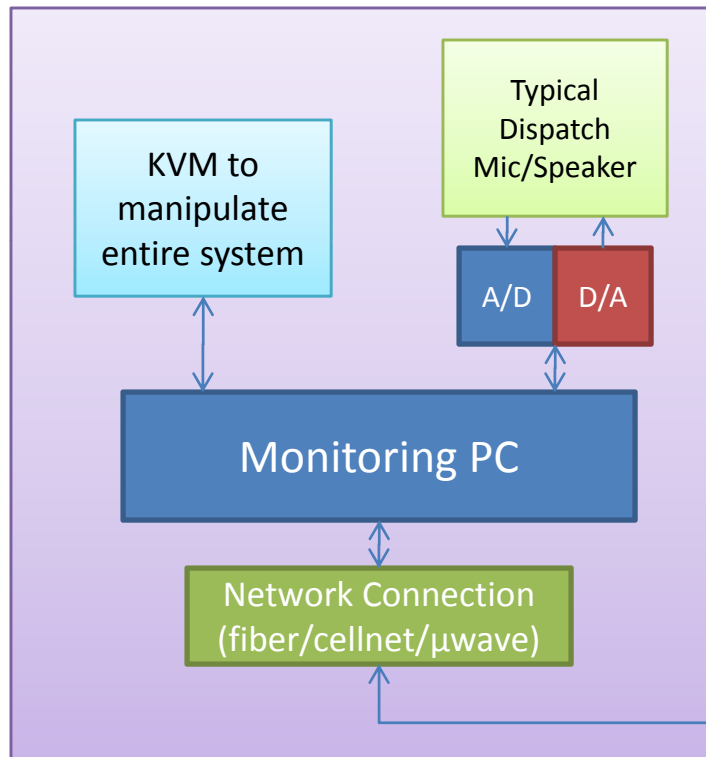
MTS/Antenna Site layout

Located at each antenna site

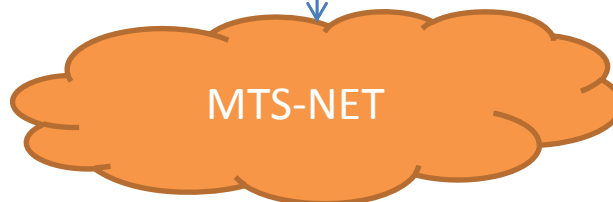
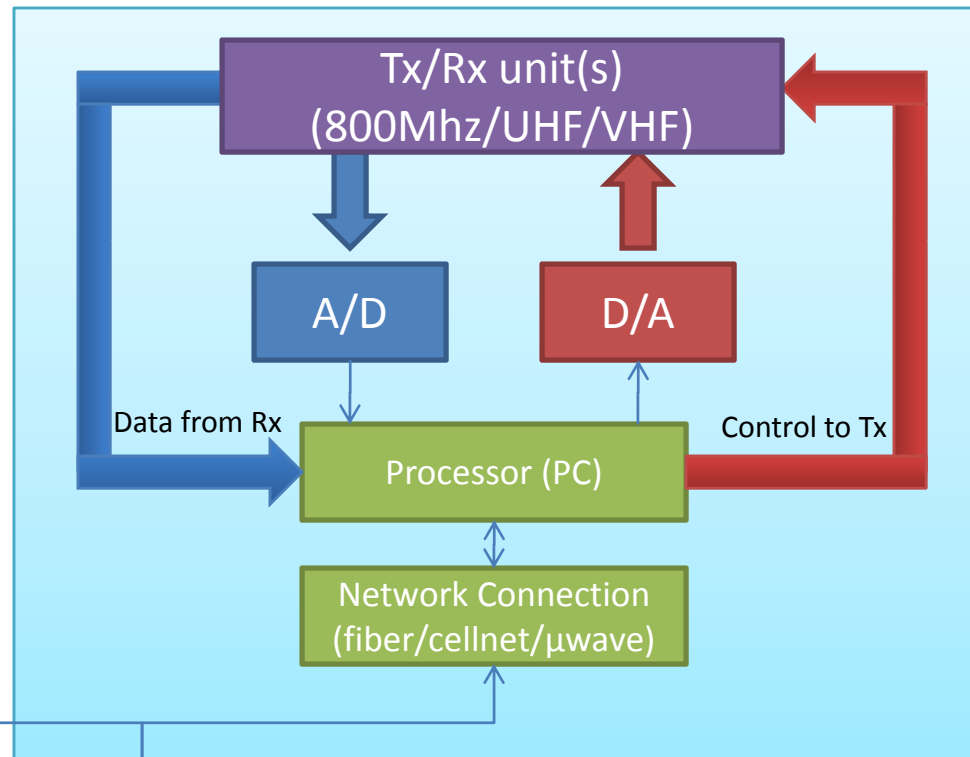


Dispatch MTS layout

At dispatch console



Can be located at dispatch Tx/Rx, server room or at console



Mini-TACSTACK (MTS)

- Features
 - Distributed voting (each site calculates it's own SNR and shares knowledge with randomly assigned MTS not actively receiving signal who decides which antenna site has the strongest signal)
 - Constantly checking for lowest latency path to dispatch center and other antenna sites
 - Dispatch Centers send configuration files to each MTS which allow each MTS unit to operate independent until told otherwise by the Dispatch Center

MTS Hardware Specs

- Distributed voting processor
- AD/DA (for Rx/Tx audio)
- Interface for gathering status from RF Tx, opening Tx channels, etc
- Network connections to other MTS units/antenna sites (fiber, copper, microwave, ...)
- PC (uses listed below)
 - Communicate with other MTS units
 - Calculate best path to/from TACSTACK (Dispatch MTS)
 - Calculating SNR of incoming RF signal (distributed voting)
 - Doing voting calculations for other MTS units

MTS-NET

- Mesh network of MTS units allowing for seamless transmission of packetized voice traffic to/from antennas
- Connectivity accomplished by:
 - Microwave systems
 - From antenna to dispatch or from remote antenna to antenna with extra hard-line bandwidth
 - Fiber/Copper
 - Provided by standard TELCO providers
 - Cellular Network Modems
 - Featuring minimum 3G modems utilizing the current major cellular networks (special contracts needed to ensure bandwidth/up-time)
- All MTS units would have battery backup and generators to allow for maximum up-time, even in extreme situations
- Minimum bandwidth required still unknown—more research into radio traffic, audio bandwidth, etc required
- All MTS units can talk to one another through mesh-style network in which all MTS units constantly optimize the best paths to communicate to one another
- MTS-NET can exist securely on public net using VPN connections where needed

Processor

- Pinging other processors for best connection
- Alerting other processors of status

Distributed Voting

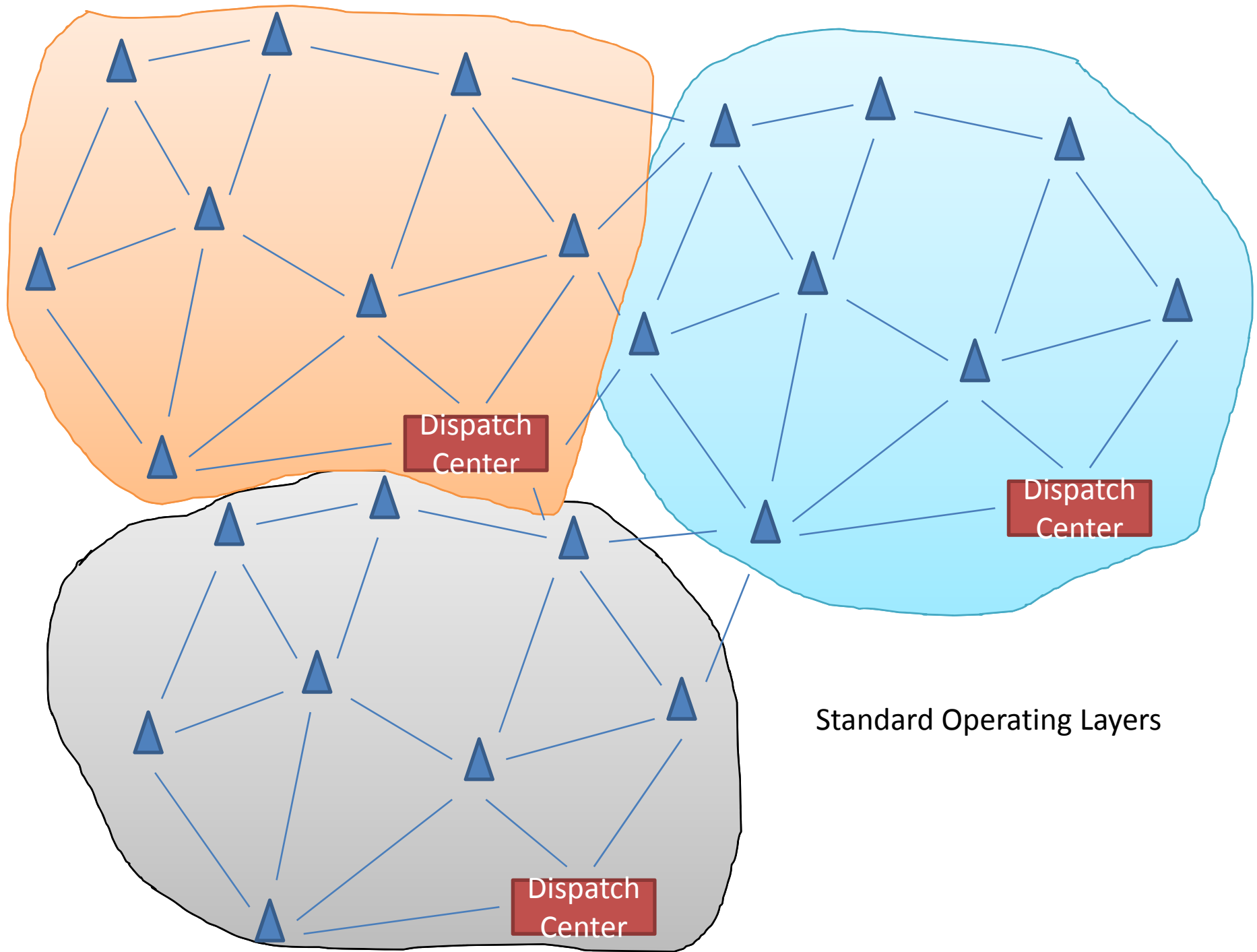
- <http://www.freepatentsonline.com/EP1589676.html>
 - “Distributed voting system and method for land mobile radio systems” patent
- <http://www.macom-wireless.com/>
 - Holds patent from link above

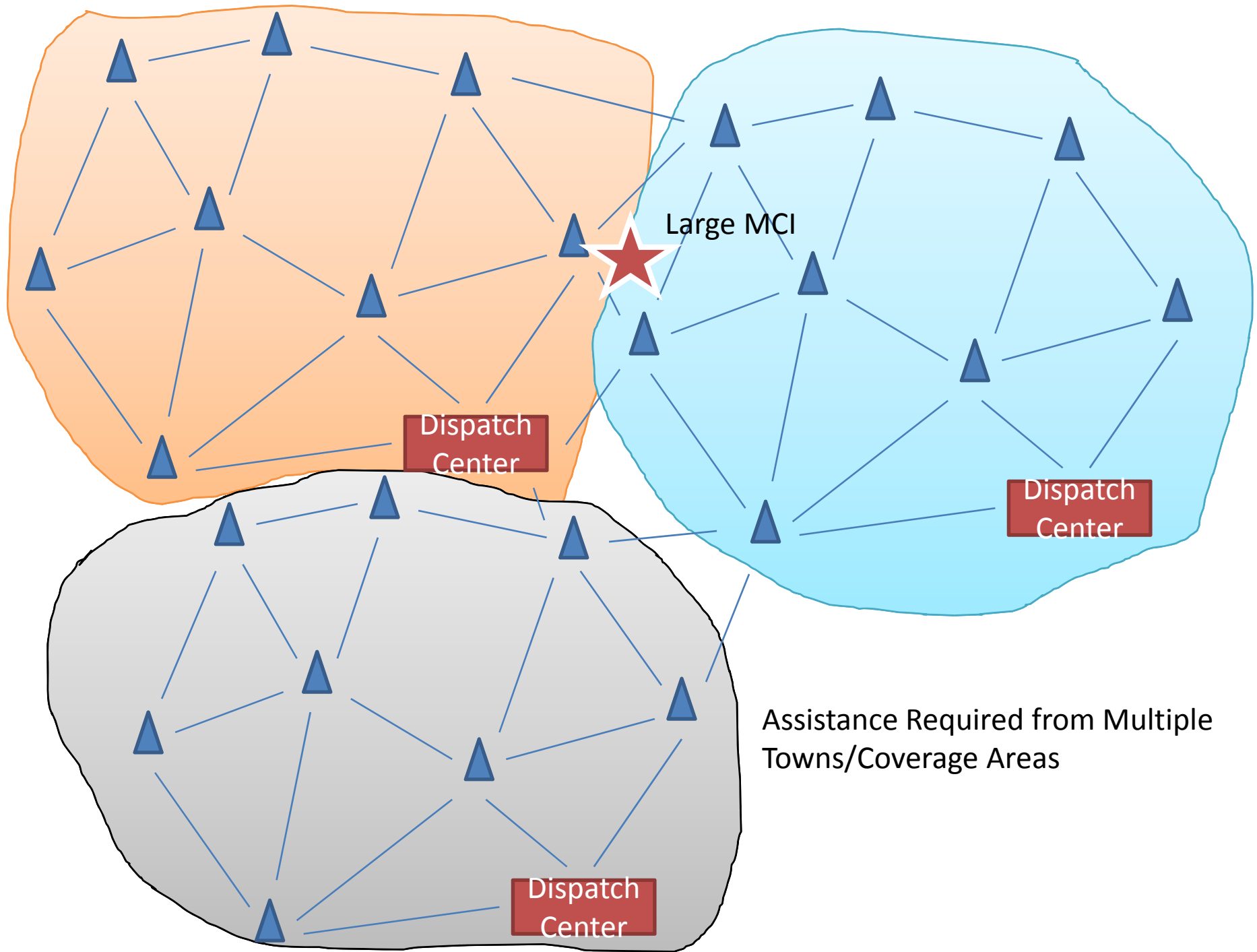
MTS components

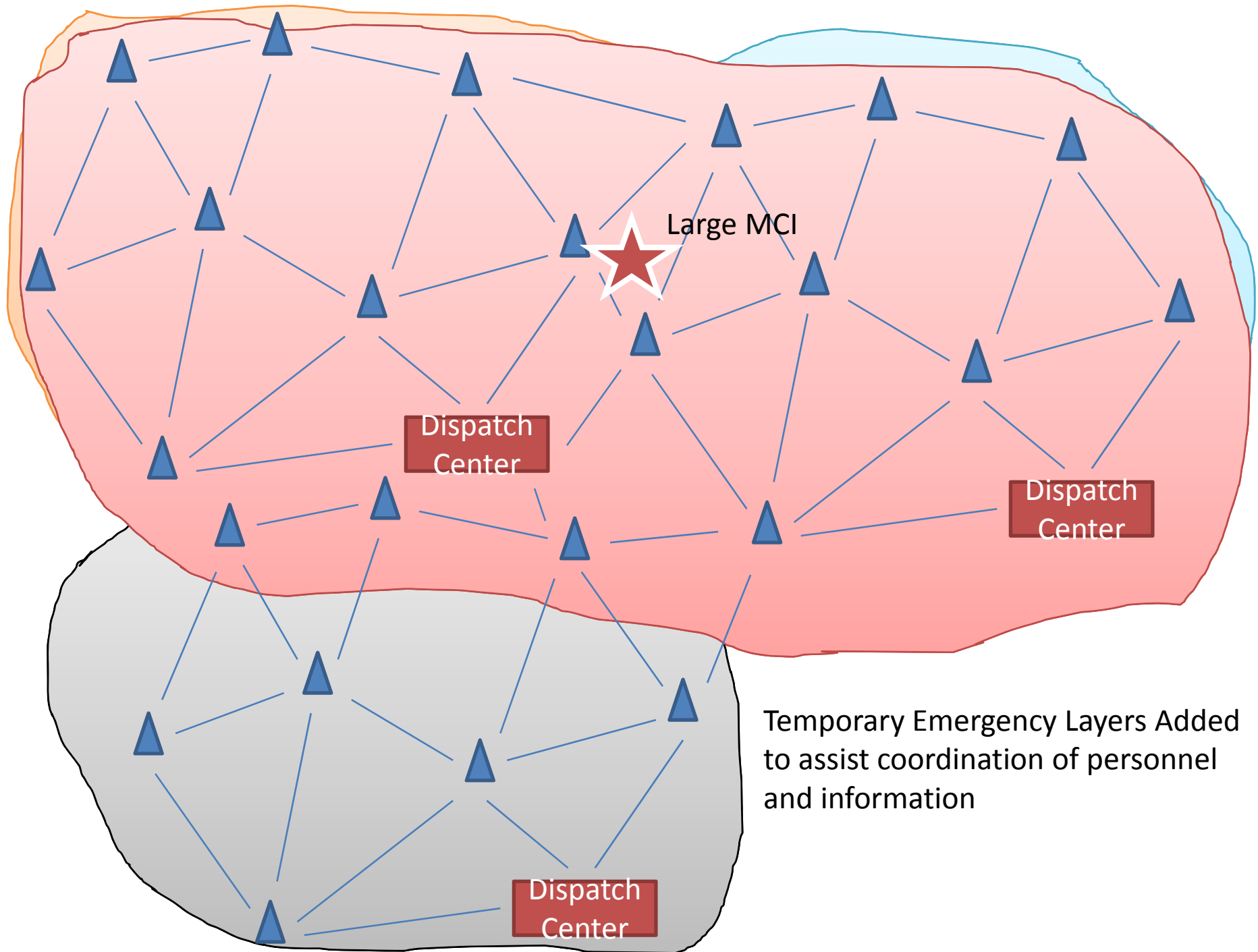
- Ruggedized PC
 - Network Interface (cell modem, NIC, microwave, etc)
 - Multi-channel ADC/DAC (<5kHz?)
 - Controllers for Tx/Rx
 - Ample processor power for:
 - Distributed voting
 - Tx/Rx control
 - Constant network optimization
- Battery backup with auto-start generator
- Transmitters and/or Receivers
- Simulcast hardware (optional)
- Extremely accurate GPS receiver (for simulcast)

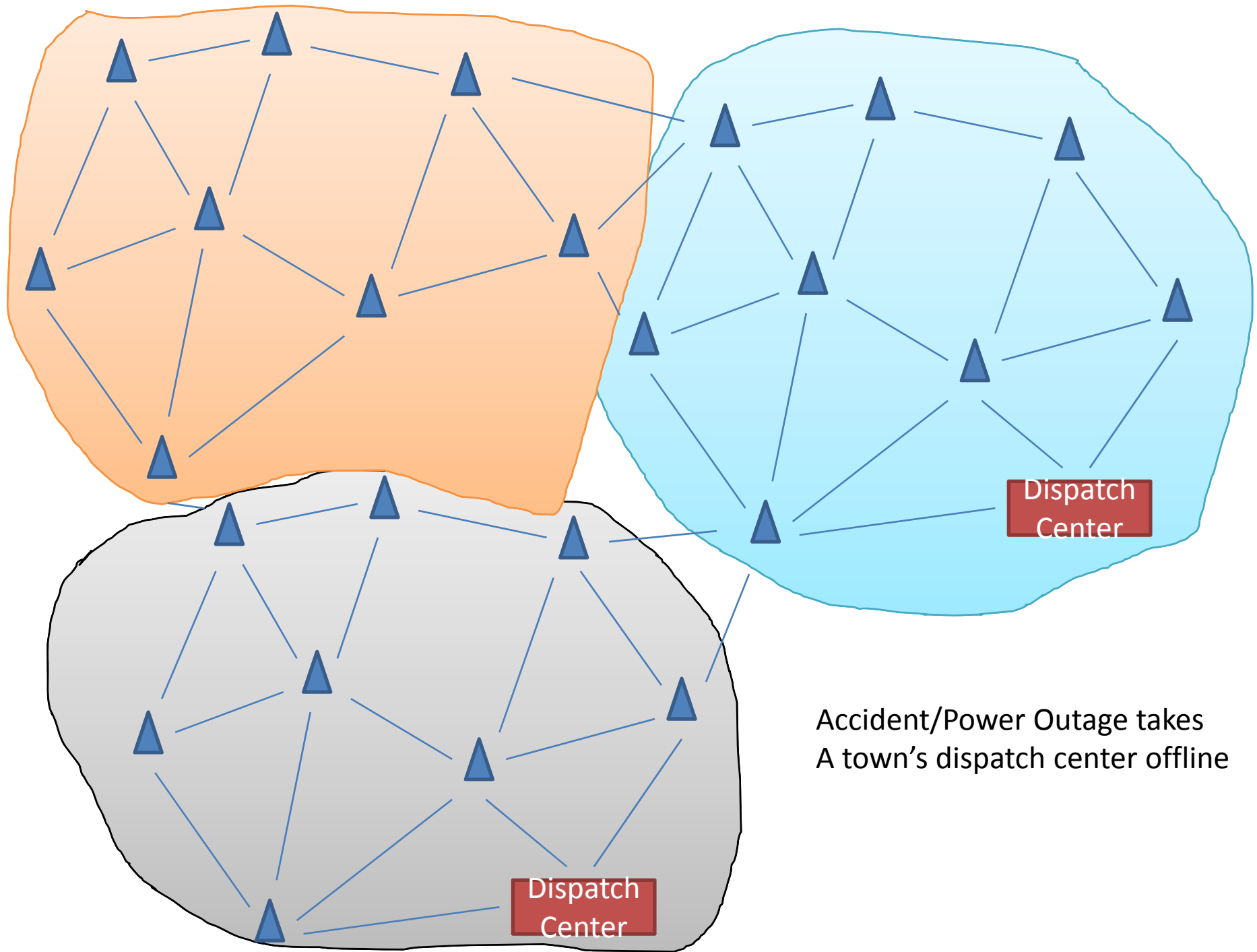
Dispatch MTS Unit

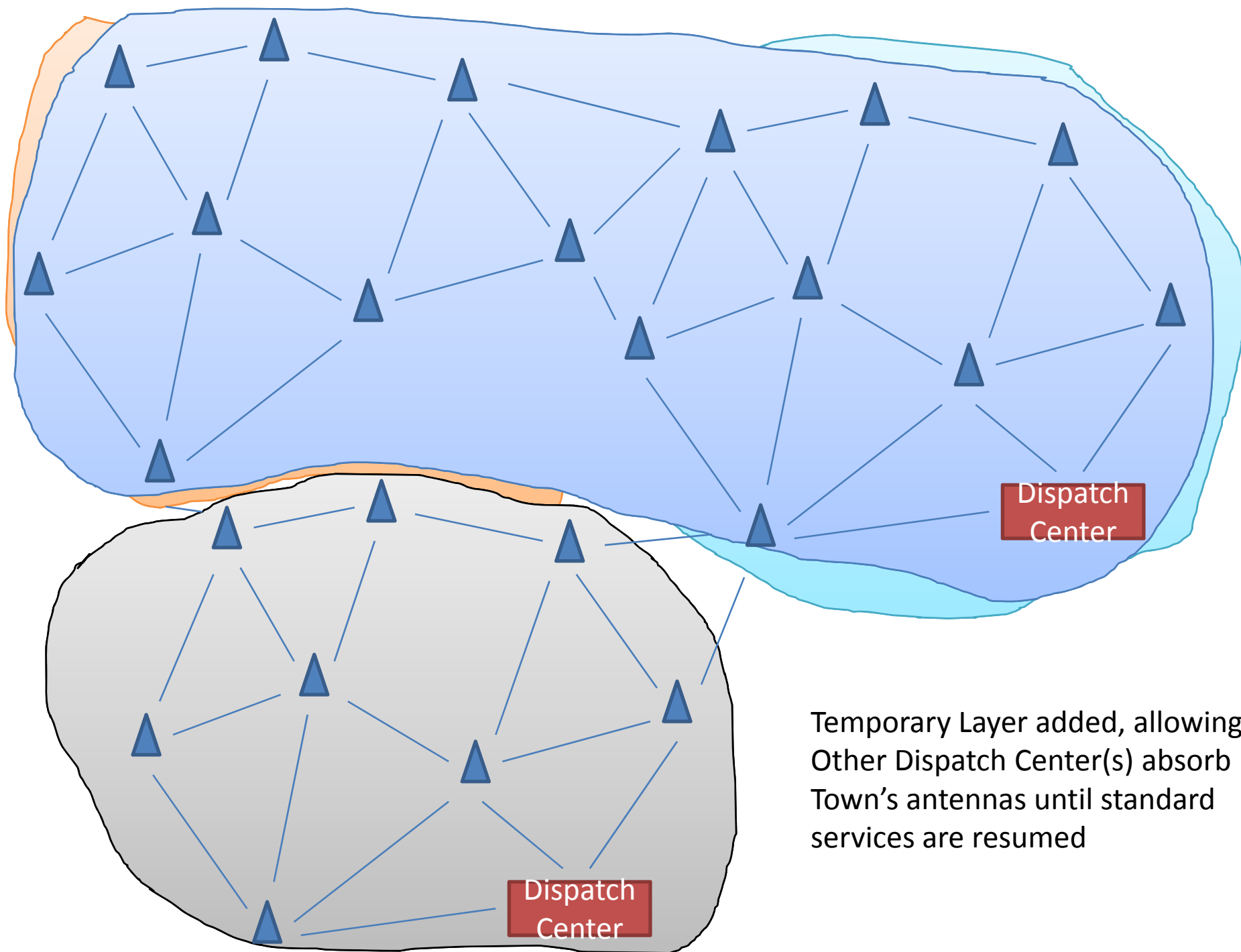
- All same features as regular MTS
- Ability to provide graphical interface of current antenna/mesh network
- Run diagnostics
- Ability to create additional antenna patch “layers” for emergency/large-scale events
 - Pass configuration files to all antennas within network
- Tx/Rx on any individual antenna
- Communicate directly with other Dispatch MTS units











Temporary Layer added, allowing
Other Dispatch Center(s) absorb
Town's antennas until standard
services are resumed

What did I forget/not even know
about?

Appendix D: TACSTACK RF Coverage Presentation

The slide show in the section was part of a presentation given by the team to Professor Michalson giving example coverage analysis of Worcester and Holden. Simulations were done in Radio Mobile.

TACSTACK Usage Model

July 8, 2008

Model Intro

- Complete simulation of an emergency situation using the TACSTACK system.
- Purpose is to identify flaws in our current logic and maybe even learn something new about ourselves in the process.

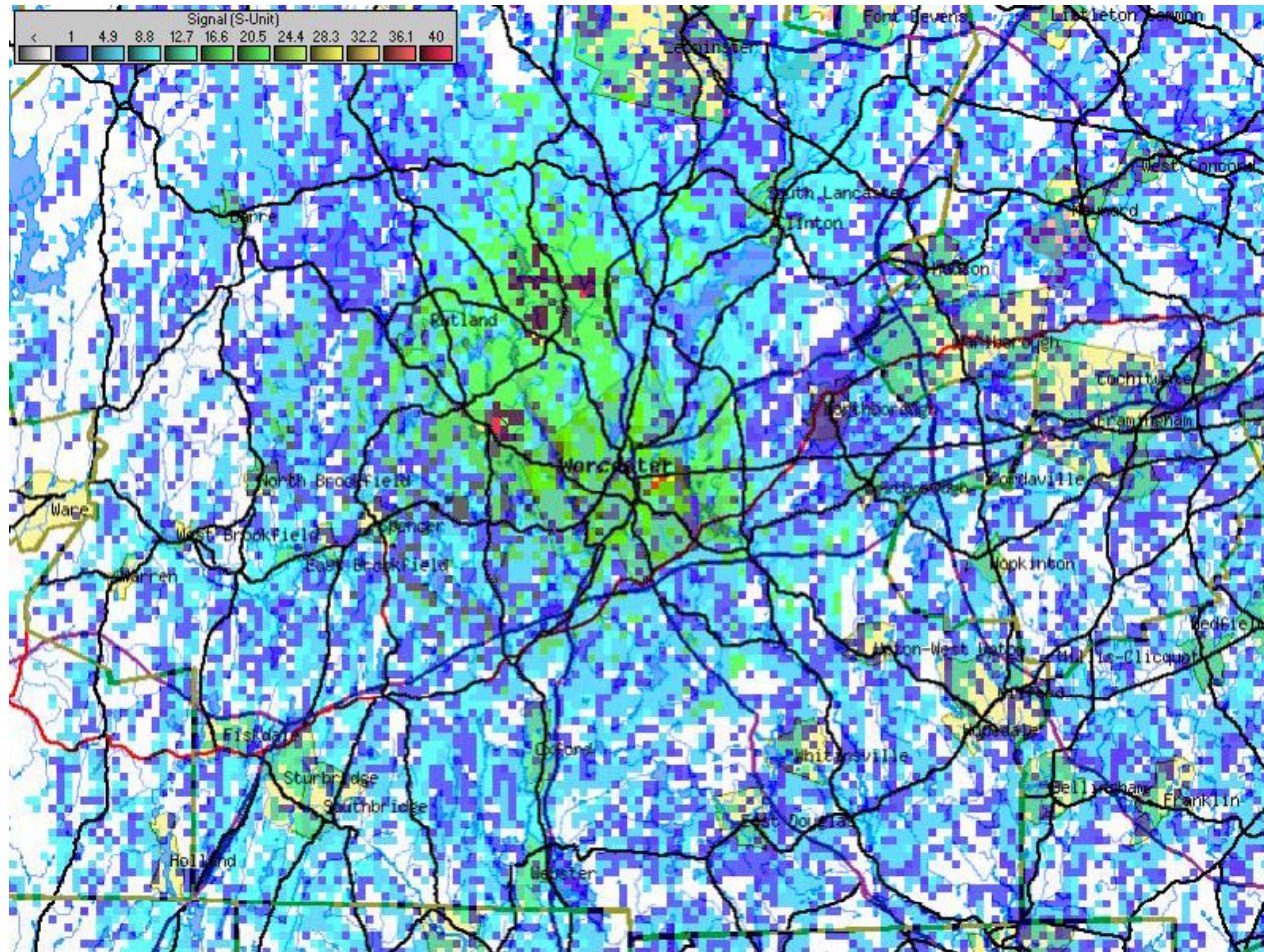
Location Info

- We chose Worcester and Holden for our model.
 - Because you told us to
 - It seemed like a reasonable enough idea.
- Worcester uses an 800MHz EDACS system
- Holden uses a more traditional 400MHz system

Initial Problems

- Worcester's trunked EDACS system may be difficult to interface with.
- Some spotty coverage between Worcester and Holden.
 - See simulation in next slide
- Both towns also have repeaters on VHF frequencies
 - Unclear as to whether we should take this into consideration

Simulation Results



First Conclusions

- One mobile repeater towards north end of Worcester
- Probably unnecessary for all towers in Holden to have mini TACSTACKs